Agricultural Bio-Fueled Generation of Electricity and Development of Durable and Efficient NOx Reduction

Project Title:

Agricultural Bio-Fueled Generation of Electricity and Development of Durable and Efficient NOx Reduction

Covering Period:

February 1, 2004 through May 1, 2007

Date of Report:

April 30, 2007

Recipient:

McMinnville Electric System
200 Morford Street
McMinnville, TN 37111-0608

Award Number:

DE-FG36-04GO14250

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Summary Abstract

Project Title:

Agricultural Bio-Fueled Generation of Electricity and Development of Durable and Efficient NOx Reduction

Objectives:

The objective of this project was to define the scope and cost of a technology research and development program that will demonstrate the feasibility of using an off-the-shelf, unmodified, large bore diesel powered generator in a grid-connected application, utilizing various blends of BioDiesel as fuel.

Furthermore, the objective of project was to develop an emissions control device that uses a catalytic process and BioDiesel (without the presence of Ammonia or Urea)to reduce NOx and other pollutants present in a reciprocating engine exhaust stream with the goal of redefining the highest emission reduction efficiencies possible for a diesel reciprocating generator.

Process:

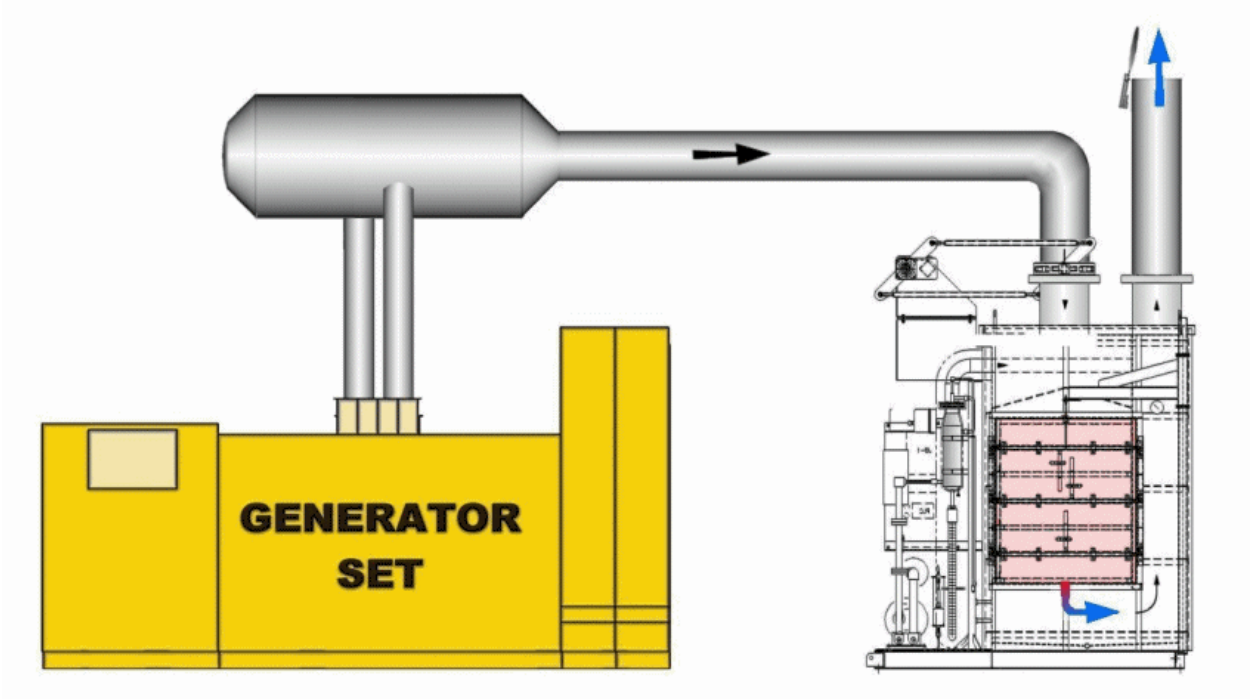
Caterpillar Power Generation adapted an off-the-shelf Diesel Generator to run on BioDiesel and various Petroleum Diesel/BioDiesel blends. EmeraChem developed and installed an exhaust gas cleanup system to reduce NOx, SOx, volatile organics, and particulates. The system design and function was optimized for emissions reduction with results in the 90-95% range; especially for NOx. TVA measured the emissions and reviewed the environmental effects.

Outcome to Date:

Objective #1 - using a 3516B Caterpillar generator, McMinnville Electric System has successfully generated 1,629,024 kWh's of renewable electric power (1008 hours of operation) using soybean based, American made BioDiesel as fuel. In the process McMinnville Electric System has used 126,126 gallons of BioDiesel which equates to 84,080 bushels of soybeans. After examining the internal rotating engine parts and combustion chamber, Caterpillar engineers report the "Test was very Successful". (See attached report BioDiesel Demonstration with SCONOx NOx Removal, Attachment "C")

Objective #2 - we were able to achieve a 96.6% reduction in NOx without the use of Ammonia or Urea as reductants utilizing EmeraChem's exhaust gas cleanup system and BioDiesel as a reductant. The NOx emission reduction results were independently measured and verified by the Tennessee Valley Authority. (See attached report BioDiesel Demonstration with SCONOx NOx Removal, Attachment "G")

Diagram of the Project:



Equipment:

3516BDITA Caterpillar Generator, EmeraChem EMx Prototype Emissions System, 30,000 gallon fuel tank, 2000 kVA power transformer, EMCP II+ Control Panel, NexGear Series 1 Advanced Paralleling Switchgear, PointGuard on-site remote-monitoring hardware.

What we have learned:

We have success proven that a large-bore stationary diesel generator can utilize 99.9% Biodiesel as fuel for a prolonged period of time, that the BioDiesel has no effect on engine durability and performance and that BioDiesel can be successfully substituted for petroleum diesel in warmer climates. We have successfully proven that NOx emissions can be reduced by > 96.6% in a large bore stationary diesel engine without the use of ammonia or urea as reductants by reforming BioDiesel into hydrogen. We have learned that you can produce >21% Hydrogen by reforming BioDiesel. We also have learned that underground mining operations and generators in non-attainment areas could benefit from the experience gained from this report.

We have not been successful in operating the BioDiesel to hydrogen reformer for extended periods of time (beyond 30 hours) without operational issues. For this type of project to be successful, the reformer would need to operate for at least 200-400 hours without maintenance, breakdown or failure. Much research is being done in this area and it is our intent

to continue our research until we have successfully overcome this obstacle. Much more detail and additional research findings can be found in the attached report entitled BioDiesel Demonstration with SCONOx NOx Removal.

History:

This project has been funded by the Department of Energy as a Congressionally Directed Project. Additional funds were provided by the American Public Power Association, National BioDiesel Board and the Tennessee Soybean Promotion Board. In-kind help was provided by EmeraChem, Stowers Caterpillar and the Tennessee Valley Authority.

Our original planned start date was February 02, 2004 with an original planned completion date of August 1, 2005. Circumstances beyond our expectations, including cold weather and total destruction of the original BioDiesel hydrogen reformer necessitated MES requesting and DOE graciously granting two (2) no-cost extensions which resulted in an actual completion date of April 30, 2007.

Disclaimer:

FOR A MORE COMPLETE EXPLINATION OF THE FINDINGS CONTAINED IN THIS EXECUTIVE SUMMARY AND ADDITIONAL INFORMATION ABOUT THE PROJECT, SEE THE ATTACHED REPORT BioDiesel Demonstration with SCONOx NOx Removal.

BioDiesel Demonstration with SCONOx NOx Removal

Award No. DE-FG36-04GO14250

Prepared for:

U.S. Department of Energy
Golden Field Office
1617 Cole Boulevard
Golden, Colorado 80401-3393

Prepared by:

McMinnville Electric System
200 Morford Street
McMinnville, Tennessee 37110

April 30, 2007

Contents

Disclaimer

The purpose of this Report is to share information about the use of BioDiesel, and a prototype NOx emissions reduction system, with all interested parties. It is furnished with the understanding that McMinnville Electric System, the City of McMinnville, Tennessee, and McMinnville Electric System's provider of power, and their respective directors, officers, agents, representatives, assigns, subcontractors, suppliers, and employees, and the McMinnville Electric System Board of Public Utilities, shall not be held liable for any claims, demands, causes of action, costs, or losses for personal injuries, property damage, or loss of life or property, arising out of or in any way connected with the testing or operation of a similar or similar Project(s), including claims based upon Breach of Contract, Breach of Agreement, Breach of Warranty, strict liability or negligence, or any other loss, damage, or injury caused by or relating to the design, manufacture, selection, delivery, condition, operation, use, maintenance or repair of a similar or similar Project(s). UNDER NO CONDITION OR CAUSE OF ACTION SHALL MCMINNVILLE ELECTRIC SYSTEM BE LIABLE FOR ANY LOSS OF ACTUAL OR ANTICIPATED BUSINESS OR PROFITS OR ANY SPECIAL, INDIRECT OR CONSEQUENTIAL DAMAGES**.**

Neither MES, the City of McMinnville, Tennessee, MES'S provider of power, nor their respective directors, officers, agents, representatives, assigns, employees, subcontractors, nor suppliers, nor McMinnville Electric System Board of Public Utilities, shall be liable for any direct, indirect, general, special, incidental, exemplary, or consequential loss or damage of any nature, including loss of life or injury, arising out of their performance or non-performance of the information provided hereunder. The provisions of this Section shall apply whether such liability rises in contract, agreement, tort (including negligence), strict liability or otherwise.

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Acknowledgements

A project of this magnitude cannot be undertaken without the help of many individuals to whom I would like to express my sincere thanks. The McMinnville Electric System Board of Public Utilities is the best utility board that a utility manager could ask for. They are among the rare leaders of an organization that will allow for and encourage "out-of-the-box" thinking. They have held me accountable throughout this Project, not in a critical way, but as an encouragement. They believe that we must protect our environment for future generations and that reliance on foreign governments to supply our fuel needs is questionable judgment. They are the true leaders of this project. Jeff Golden (chairman), Sam Martin (vice-chairman and R&D Committee member), Jeff McKinley (R&D Committee chairman), Bobby Kirby (aldermanic representative and R&D Committee member) and Sally Brock (board member) should be thanked by our community for the commitment they, individually and as a Board, have to this organization. Robert Newman (general counsel) has also been an invaluable resource when it came to negotiating Purchase Power Agreements and Parallel Operating Agreements with TVA.

Congressman Lincoln Davis cannot be thanked enough for his sponsorship of this Project and his interest during the entire process. He and his staff (Beecher Fraser, Brandi Lowell and Cicely Simpson) have been fantastic to work with, during the last two years. Congressman Davis has a commitment to American farmers that is second to none in Congress. To me, he is an American hero in our Nation's capitol. Tennessee owes him many, many thanks!

Steve DeCicco and Lisa Mitchell (EmeraChem) have been by my side through the good times and bad. We have both raised our hands in victory during this Project and suffered agonizing moments when it appeared the obstacle before us was insurmountable – many times in the same day – sometimes within the same hour. Had it not been for their spirit of adventure and thirst for inventiveness, this Project would not have achieved the success that we have enjoyed. To them, a place in my heart and life will always abide. I would also like to thank Tom Girdlestone (EmeraChem) for allowing Steve and Lisa to continue to work on this project and to see it through to success.

Ralph Dunn and Huel Martin (McMinnville Electric System) have been the hands and engineering minds of this Project since it was first conceived back in 2001. They have literally worked day and night to make it successful; and without them beside me helping, and behind me pushing, I could not have made this Project a reality. My substation maintenance crew (Jonathan Womack, Troy Sauls and Jeremy Womack) worked throughout the night on many occasions to wash the catalyst and have them ready to reinstall and operate the next morning. The McMinnville Electric System line crew (Billy Pitmon, Gene Rhea, Tony Foster, Frankie Rains, Phillip Rowland, Craig Foster, Dwight Jones, Neal Smith and Jonathan Jacobs) installed the generator, all of the switchgear and wiring. What a remarkable group of craftsmen.

Neal Cox (McMinnville Electric System) has been the finance and accounting mind behind the Project. Neal has worked tirelessly behind the scenes to make sure all of the accounting "i's" are dotted and "t's" are crossed and has been responsible for compiling the mounds of paperwork that must be supported during the Project. Neal is also a diligent champion of alternative fuels and believes that helping American farmers is in our nation's best interest.

Dave Brown and Joey Wilcher (Phillips Sales and Service) were the brawn and brains for the fuel delivery and filtration system. You can have the best fuel and the best storage facility, but if you can't get the fuel from the tank to the engine, you don't have anything. They were available at a moment's notice, 24-hours a day. When we needed help – anytime – they were there quickly. Their help and guidance through all the fuel blend testing was immeasurable – I give them thanks.

Ralph Boroughs (TVA) was a skeptic at first and later one of my most wholehearted supporters. His first and foremost objective is environmental protection; and at that, he is great. The first time Ralph and I met, you could tell from his non-verbal communication that there was no way that he was going to support a project like this. After he found out our goal was >90% NOx reduction, we had his attention and his arms-crossed demeanor changed as well The day we achieved the 96.6% NOx reduction target, he was the one with the biggest smile on his face. Ralph Boroughs is a great guy and a good friend. Chevales Ward and Duane Brigman (TVA) were also of utmost help to the Project. During one particular emissions test, it was raining strait down and no one would have faulted Chevales and Duane for stopping the test and coming in out of the rain; however, these two committed environmental champions worked throughout the rain storm because they knew how tight our testing schedule was and that stopping at that point would have meant a week's setback. Thank you Chavales and Duane for a moment that I will not soon forget.

Others I would like to thank include Parks Wells (Tennessee Soybean Promotion Board), Tom Stanzione (Stowers/Caterpillar), Dave Martin (Stowers Caterpillar), Kelly Strebig (University of Minnesota Center for Diesel Research), Helen Hennon (Quantum Environmental and Engineering), Jonathan Overly (East Tennessee Clean Fuels Coalition), Ryan Strickland (Agri-Energy), Bill Ayers (AgBioEnergy), Gary Ewing (SECOR International), Mike Kossey (USDA), the American Public Power Association and Dr. Albin Chernichowski (GlidArc Technologies) who flew here from France to be part of this Project.

Also, I would like to thank Ms. Jane Flatt (McMinnville Electric System) for all her hard work and help. Jane is a one-in-a-million help and confidant. Among those who possess great literary skills, she stands as a giant; and among other traits, has the ability to make my documents look and read much better than I can write.

Finally, I would like to thank my wife who has endured countless trips to the generation substation in the middle of the night to bring me items which I need; forgiven me for the numerous times when all I had time to do was run in the house, change clothes, and run back out the door again because I was needed at the Project jobsite; and for all the nights that she has been kind enough to leave a light shining so I could see to get in the door after a long day of emissions testing.

Award Project Final Report

Project Title:

BioDiesel Demonstration with SCONOx NOx Removal

General Overview:

The purpose of the study was to demonstrate the ability of an EMx catalyst to clean the emissions from a large stationary diesel reciprocating engine. EMx had been previously demonstrated on a 50 kW diesel reciprocating engine using regeneration via direct fuel injection into the catalyst. EMx has been in commercial practice on gas turbines. This demonstration project involved scaling up the reciprocating engine experience and scaling down the gas turbine experience. It also involved a new, emerging regeneration technology capable of utilizing liquid fuels (LSD, ULSD, BioDiesel, etc.) and a plasma reformer.

The catalyst used for the test was standard EMx, utilizing K_2CO_3 sorber on a barium-alumina washcoat. The catalysts were on 200 cpsi cordierite substrates. Four rows of EMx catalyst were installed in each chamber, with two 18" x 42" x 6" modules per row. The total catalyst volume for each catalyst chamber was 21 ft^3. Sulfur management was handled by frequent washing of the catalyst; no ESx (sulfur) catalyst was installed. The catalyst regeneration gas was supplied by a plasma reformer fueled by the parent (native) fuel.

The engine utilized in the Project was an off-the-shelf 3516B EPG Caterpillar engine (build date 8/20/2004) with 2293 bhp coupled to a Caterpillar SR4B generator and capable of producing 1640 kW @ 60 Hz continuous. The engine has a 4.46 g/bhp-hr NOx emission rating. This particular engine was selected by Caterpillar because it is their most popular large-bore engine for stationary applications. This engine can be found around the country in back-up and standby power generation applications. Engine performance was remotely monitored by Caterpillar and emissions performance was monitored by the Tennessee Valley Authority across a wide spectrum of fuels including: 100% ULSD (ultra-low sulfur diesel), a blend of 2% soybean biodiesel and 98% ULSD, a blend of 5% biodiesel and 95% ULSD, a blend of 20% biodiesel and 80% ULSD, a blend of 50% biodiesel and 50% ULSD, and 100% biodiesel.

Purpose:

To demonstrate the feasibility of using an off-the-shelf, unmodified, large bore diesel powered generator in a grid-connected application, utilizing various blends of BioDiesel as fuel. In addition, a first-of-its-kind emissions control device that uses a catalytic process and BioDiesel (without the presence of Ammonia or Urea) was developed to reduce NOx and other pollutants present in a reciprocating engine exhaust stream.

This Project was initiated with the belief that America must become less reliant on foreign sources of fuel (i.e., petrol diesel) and become more aware of the effect that engine exhaust gasses have on our health and our environment.
Soybeans represent a large segment of the world's agriculture, and in terms of gross production, soybeans are the dominant oilseed crop[1]. They absorb light from the sun (solar energy), water from the earth (hydro energy) and CO_2 from the air (wind energy) and convert that stored energy into natures own battery (stored energy). Soybeans therefore become the greatest fuel treasure that we produce and harbor on American soil and should also be recognized as one of our greatest sources of renewable energy.

This Project is intended to provide information that fuel can be domestically produced, refined and utilized to provide clean, renewable power for American homes and businesses. All this, while providing economic incentives for farmers to make the most of fallow farmland, to provide a return on their investment and to invest that money back into our Nation's economy.

Utility Name and Address:

McMinnville Electric System
200 Morford St.
P.O. Box 608
McMinnville, TN 37110

Other Participants:

EmeraChem
Stowers/Caterpillar
Tennessee Valley Authority
American Public Power Association
National BioDiesel Board
Tennessee Soybean Promotion Board
Agri-Energy, LLC

Utility Description:

Size: 7860 Electric Customers
Annual Load: 243,682,957 kW
Services Offered: Surge Protection
Generation Resources: 22 MW peaking plant
Other: 217 miles of line, 36 Customers/mile, 2 delivery points

[1] Bajjalieh, N., 2002, Proteins from Oilseeds, Integrative Nutrition, Inc. (Research note)

Key Personnel and Phone Numbers:

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Other

Helen Hennon – Director of Governmental Services, Quantum Environmental & Engineering Services, LLC – (865) 689-1395
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Kelly Strebig – University of Minnesota Center for Diesel Research - (651) 330-0450
Will Ayers – V.P. Engineering, Cim-Tech Filtration – (217) 678-2511
Dr. Thomas Reed – Biomass Energy Foundation – (303) 279-3707
William Ayres – AgBioEnergy, LLC – (913) 341-7114
Dave Brown – Phillips Sales and Service – (931) 473-2450

Description:

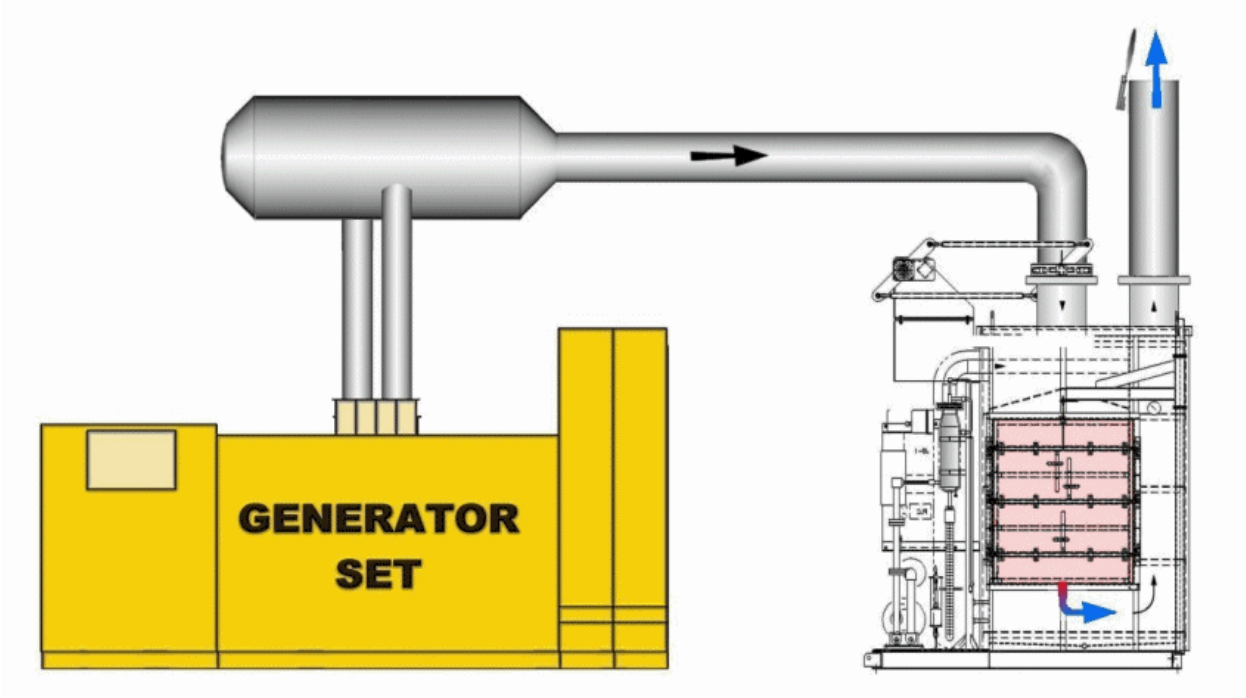
The objective of this project was to define the scope and cost of a technology research and development program that will result in ammonia free, pollution reduction system with the highest emission reduction efficiencies possible for the electric industry.

Caterpillar Power Generation adapted an off-the-shelf 3616 BDITA Diesel Generator to run on BioDiesel and various Petroleum Diesel/BioDiesel blends. EmeraChem developed and installed an exhaust gas cleanup system to reduce NOx, SOx, volatile organics, and particulates. The system design and function was optimized for emissions reduction with results in the 90-95%

range; especially for NOx. TVA measured the emissions and reviewed the environmental effects.

See Attachment “B” for a thorough discussion on the EMx Prototype test, Attachment “C” for Caterpillar’s engine analysis results and comments and Attachment “D” and “E” for information on GlidArc Technology.

Diagram of the Project:



Dates:

The DEED Grant Agreement between McMinnville Electric System and the American Public Power Association was signed in February of 2005 and the project was completed in April 2007.

Alternatives:

Alternatives to the Project include: operating the generator engine without the use of external pollution controls; the use of a conventional Selective Catalytic Reduction (SCR, ammonia or urea injection system); the use of other NOx emission control technologies (lean NOx catalyst, three-way catalyst, etc.); the use of lesser blends of BioDiesel (B-2, B-5, B-10, B-20, etc.).

Results to Date:

Using a 3516B Caterpillar generator, McMinnville Electric System has successfully generated 1,629,024 kWh's of renewable electric power using soybean based, American made BioDiesel as fuel. In the process McMinnville Electric System has used 126,126 gallons of BioDiesel which equates to 84,080 bushels of soybeans.

In addition, we were able to achieve a 96.6% reduction in NOx without the use of Ammonia or Urea as reductants.

Status:

Complete

Applicability:

Other utilities, especially those in non-attainment areas and environmentally sensitive areas, could use the results of this Project to site diesel powered generations in their area without the adverse environmental impact of untreated diesel exhaust emissions or the environmental impact of ammonia slip in the exhaust stream.

The underground mining industry would also benefit from the environmental findings of this Project; both on the use of BioDiesel in underground stationary generation and from the use of a catalytic NOx trap.

Utilities outside of the United States could use the results of this Project to site generation in areas that are remote; and thus, hard to deliver fuel to the site, by producing BioDiesel from palm oil, rape seed oil, canola oil, etc. local to the generation facility. One example is an inquiry that I have had from a location deep in the heart of Africa that has an abundance of palm oil. Transportation of petrol diesel to this area is difficult and expensive but the ability to site a BioDiesel refinery and install diesel generation is within the ability of the area.

Future Plans:

Future studies should include long-term studies of the effects of BioDiesel on the catalyst. All future studies hinge on the availability of reliable regeneration technologies, TVA's acceptance of BioDiesel fueled generation and their willingness to purchase the energy output of a BioDiesel fueled generation facility. If TVA is willing to purchase electric energy produced by the combustion of BioDiesel from this Project, McMinnville Electric System will work with EmeraChem and other partners toward development and automation of a durable plasma regeneration technology that will result in a robust, efficient and clean NOx removal technology.

Future plans should also include the development and construction of a more efficient and stable plasma regeneration technology possibly utilizing GlidArc-III technology. (see Attachment

"E") and a long term durability test (>10,000 hours) on the Caterpillar motor/generator, in a grid-connected application, using B-99.9 as fuel.

Equipment:

Generator:

Engine: Caterpillar 3616B	Duty: CONTINUOUS	Connection: SER STAR
Generator Frame: 826	Type: SR4B	No. of Bearings: 2
Generator Arr: 1441826	Housing: 00	Winding Type: FORM WOUND
Genset Rating (kW): 1640 (kVA): 2050.0		Sync Speed: 1800
Voltage: 277/480 3 phase	Frequency: 60 Hz	Pwf. Factor: 0.8
Rated Current: 2465.8	Gen. Pitch: 0.7143	No. of Leads: 6

EmeraChem EMx Prototype Emissions System, 30,000 gallon fuel tank, 2000 kVA power transformer, EMCP II+ Control Panel, NexGear Series 1 Advanced Paralleling Switchgear, PointGuard on-site remote-monitoring hardware.

Performance:

Caterpillar Generator: No downtime due to engine, internal moving components in excellent condition, hose/seal material acceptable for <B-30 but needs to be modified for operating on B-100, engine test was very successful.

EmeraChem EMx Prototype: The EMx catalyst system performs at greater than 90% NOx removal, even with very high inlet NOx concentrations and operating temperatures of 750˚F. The EMx system eliminates the visible plume and significantly silences the engine exhaust.

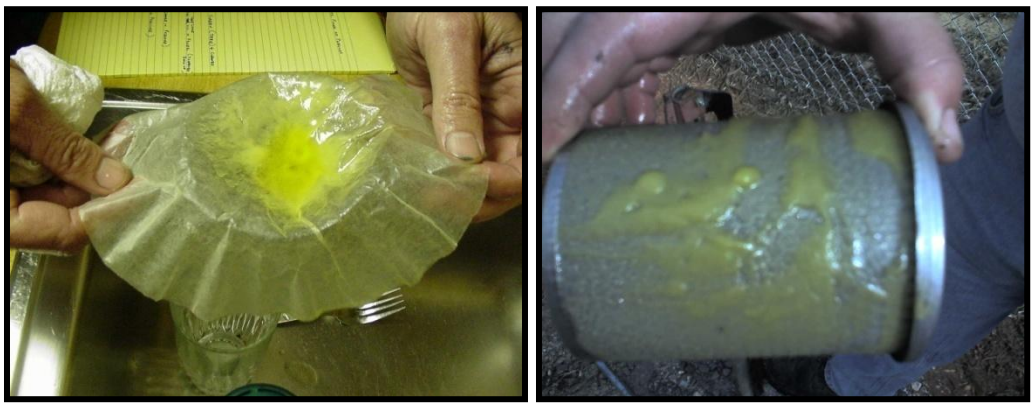
One significant discovery was that as the fuel blend progressed from ULSD to B-100 the ability of the Caterpillar generator to export power to the grid went down accordingly. Upon Caterpillar's review it was noted that BioDiesel had approximately 10,000 less Btu's per gallon than ULSD and that the engine was in essence starving for fuel. When we attempted to adjust kW output beyond the load kW noted below, the engine would shut-down and bring testing to a halt. Caterpillar dispatched a technician to the job site and made a change to the throttle position sensor that allowed the engine to operate beyond the throttle limit and we were able to generate at a full 1640 kW. On several occasions we operated at 1650 kW to see how the engine would respond.

Also of interest was the fuel consumption as we progressed from ULSD to B-100. As you can tell from the chart below, fuel consumption increased as the fuel blend decreased. Later, fuel consumption was checked on many other occasions at 1640 kW with B-99.9 and was found to be +/- 2% of 123 gph. Fuel consumption was calculated using a stopwatch and the change in fuel level in the generator day-tank.

Date	Fuel	Load kW	GPH Fuel Consumption	kW/Gallon
7-Jul-05	ULSD	1625	120.00	13.54
8-Jul-05	B-2	1625	118.79	13.68
8-Jul-05	B-5	1625	120.60	13.47
9-Jul-05	B-20	1560	122.61	12.72
9-Jul-05	B-50	1545	123.33	12.53
10-Jul-05	B-100	1495	126.00	11.87

Fuel blending for all tests from B-2 through B-50 was conducted by an engineer and carefully calibrated using a certified Seraphin Model FS282 Field Standard Test Measure.

Fuel quality issues plagued us throughout the testing process and resulted in McMinnville Electric System using fuel from three different BioDiesel refineries. Test results from samples taken during the test showed anywhere from high levels of methanol (see Attachment ”A”) to high levels of glycerin. Pictures depicting some of our fuel quality struggles are shown below.



Fuel batch testing results are listed below:

ASTM #	test name	Unit	Max	Min	batch1	batch2	batch3	batch4	batch5	batch6	batch7	batch8
D6584	Free Glycerin	% mass	0.02		0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
D6584	monoglycerides				0.814%	0.792%	0.793%	0.671%	0.554%	0.633%	0.814%	0.693%
D6584	diglycerides				1.872%	1.563%	1.450%	0.851%	0.816%	0.633%	1.076%	0.952%
D6584	triglycerides				9.530%	8.422%	6.781%	2.566%	2.546%	2.031%	4.227%	3.568%
D6584	Total Glycerin	% mass	0.24		**1.484%**	**1.317%**	**1.129%**	**0.568%**	**0.531%**	**0.478%**	**0.812%**	**0.694%**
D93	Flash Point	˚C		130	172	174	174	166	167	172	171	177
D2709	Water & Sediment	vol%	0.05		0.050%	0.050%	0.040%	0.040%	0.050%	0.040%	**0.120%**	
D874	Ash, Sulfated	% mass	0.02									
D5453	Total Sulfur	% mass	0.05		0.0001%	0.0000%	0.0000%	0.0001%	0.0001%	0.0001%	0.0000%	
D664	Acid Number	mg KOH/g	0.8		0.390	0.250	0.250	0.220	0.280	0.170	0.250	0.280
Cc17-95	Soap	ppm			19			15				
D130	Copper Corrosion		#3									1a
D445	Kinematic Viscosity	mm/s	6	1.9	5.643	5.426	5.164	4.677	4.412	4.320	4.463	4.583
D524	Carbon Residue, Ramsbottom	% mass	0.05		**0.060%**	**0.200%**	0.040%	0.030%	0.042%	0.040%	0.044%	0.010%

As the above table illustrates, fuel quality is a major concern going forward with the Project.

Of significant note was engine oil consumption. All large-bore stationary diesel engines are expected to consume a certain amount of oil during the engine duty cycle. Because a diesel powered generator in a grid-connected application operates under high load conditions and near the top of its horsepower range, some oil will naturally make its way past the piston rings and be ignited in the combustion process. This is natural and expected.

Our experience with the other 11 large-bore stationary diesel generators that McMinnville Electric System owns and operates has shown that a diesel generator will consume approximately one (1) gallon of oil for every six (6) hours of operation under normal load (generation) conditions. It was noted early in the operation of the Project that the generator engine was not using the same amount of oil as would have been expected. After 1008 hours of operation, the Caterpillar 3516B engine consumed 25 gallons of oil which is 0.025 gph as compared to our experience consumption of 0.167 gph. This represents an 85% reduction in oil consumption comparing expected with actual.

The test 3516B was equipped with a self-oiler from the Caterpillar factory and there was some concerned that the oiler was not operating properly or that some other issue was happening that we were unaware of. After review by a Caterpillar technician, there was no operational reason found why the engine was not consuming oil at the same rate as would be expected. It was theorized that the difference in lubricity between diesel fuel and BioDiesel might be a determining factor to the difference or that oil was bypassing the piston rings and making its

way down into the crankcase resulting in lube-oil dilution. Without quantifiable data (operation of the engine for >10,000 hours) it will remain a theory and a mystery.

Caterpillar took oil samples and had analysis performed at 1, 235, 500, 800 and 1007 hours of operations. Results are shown below:

NEW CAT ENGINES FOR SALE

FAX:
PHONE:

SAMPLE TYPE: OIL

COMPANY NAME : NEW CAT ENGINES FOR SALE
CUSTOMER EQUIP NUM : FDN01567
COMPARTMENT NAME : ENGINE
SERIAL NUMBER : FDN01567
MANUFACTURER : CATERPILLAR
MODEL : 3516B
JOB SITE : REPORT D MARTIN
EXT WARR NUMBER :

SHOP JOB NUM :
COMP SERIAL NUM :
COMPARTMENT MODEL :
COMP MANUFACTURER :
SAMPLE LABEL NUM :
FLUID BRAND/WEIGHT : CATERPILLAR/15W-40
FLUID TYPE :
EXT WARR EXPIRE DATE :

Stowers CAT
6301 Old Rutledge Pike
Knoxville, TN 37924
(865) 595-1028
stowers.cat.com

LAB CONTROL NUMBER	SAMPLE DATE	PROCESS DATE	EQUIPMENT METER	METER ON FLUID	FLUID CHANGED	MAKE UP FLUID	MAKE UP FLUID UNITS	FILTER CHANGED
D390-37009-0032	1/3/07	1/9/07	1007 HR	1007 HR	No			
Action Required	SODIUM CONTINUES TO BE ABOVE NORMAL. IRON AND LEAD ARE STILL ABOVE NORMAL. HIGH IRON AND LEAD COULD INDICATE EXCESSIVE ROD AND OR MAINE BEARING WEAR. INSPECT FOR SOURCE OF HIGH IRON AND LEAD. RESAMPLE AT 1/2 THE NORMAL INTERVAL TO MONITOR THE IRON AND LEAD.							
D390-36320-0070	11/14/06	11/16/06	800 HR	300 HR	No			Unknown
Action Required	SODIUM IS STILL ABOVE NORMAL. COPPER, IRON AND LEAD HAVE INCREASED FROM LAST SAMPLE. SUGGSET REDUCING OIL CHANGE INTERVAL TO 250 HOURS.							
D390-36241-0023	8/28/06	8/29/06	500 HR	266 HR	No			No
No Action Required	SODIUM IS REPORTABLE. ALL WEAR METALS ARE ACCEPTABLE. SODIUM (SALT) ALONE MAY BE FROM SOME TYPE OF CLEANING SOAP. CONTINUE SAMPLING AT THE NORMAL INTERVAL.							
D390-36080-1038	3/20/06	3/21/06	234 HR	234 HR	Unknown		L	Unknown
No Action Required	ALL READINGS ARE ACCEPTABLE.CONTINUE SAMPLING AT THE NORMAL INTERVAL.							

Wear Metals (ppm)	Al	Ca	Cr	Cu	Fe	Pb	Mg	Mo	Ni	P	K	Si	Na	Sn	V	Zn
D390-37009-0032	2	2597	1	49	54	12	305	2	0	1236	3	5	57	0	0	1429
D390-36320-0070	2	2621	1	53	44	12	340	4	0	1215	6	5	68	1	0	1405
D390-36241-0023	1	3126	1	34	22	3	360	6	0	1463	4	4	62	1	0	1770
D390-36080-1038	0	2772	1	7	11	1	364	4		1350	5	6	42	0		1559

Oil Condition / Particle Count (ct/ml)	ST	OXI	NIT	SUL	W	A	F	PFC	V100	TBN
D390-37009-0032	40	45	15	36	N	N	N		14.4	
D390-36320-0070	44	44	14	37	N	N	N		12.5	
D390-36241-0023	23	30	10	28	N	N	N	0.65	11.3	
D390-36080-1038	50	86	7	11	N	N	N		10.7	7.3

Ag = Silver, Al = Aluminum, B = Boron, Ca = Calcium, Cr = Chromium, Cu = Copper, Fe = Iron, P = Phosphorus, K = Potassium, Mg = Magnesium, Mo = Molybdenum, Na = Sodium, Ni = Nickel, Pb = Lead, Si = Silicon, Sn = Tin, V = Vanadium, Zn = Zinc, A = Antifreeze, F = Fuel, W = Water, P = Positive, N = Negative, T = Trace, E = Excessive, NIT = Nitration, OXI = Oxidation, ST = Soot, SUL = Sulfation, ISO = ISO Rating, PQI = Particle Quantifying index , NaW = Salt Water, FL Pt = Flash Point, TAN = Total Acid Number, TBN = Total Base Number, H2O = Karl Fisher result, V100 = Viscosity@100C, V40 = Viscosity@40C

Notice: This analysis is intended as an aid in predicting mechanical wear. No guarantee, expressed or implied, is made against failure of this piece of equipment or a component thereof.

NEW CAT ENGINES FOR SALE

FAX:
PHONE:

SAMPLE TYPE: OIL

COMPANY NAME : NEW CAT ENGINES FOR SALE
CUSTOMER EQUIP NUM : FDN01567
COMPARTMENT NAME : ENGINE
SERIAL NUMBER : FDN01567
MANUFACTURER : CATERPILLAR
MODEL : 3516B
JOB SITE : REPORT D MARTIN
EXT WARR NUMBER :

SHOP JOB NUM : K-15869
COMP SERIAL NUM :
COMPARTMENT MODEL :
COMP MANUFACTURER :
SAMPLE LABEL NUM :
FLUID BRAND/WEIGHT : CATERPILLAR/15W-40
FLUID TYPE :
EXT WARR EXPIRE DATE :

Stowers CAT
6301 Old Rutledge Pike
Knoxville, TN 37924
(865) 595-1028
stowers.cat.com

LAB CONTROL NUMBER	SAMPLE DATE	PROCESS DATE	EQUIPMENT METER	METER ON FLUID	FLUID CHANGED	MAKE UP FLUID	MAKE UP FLUID UNITS	FILTER CHANGED
D390-36241-0023	8/28/06	8/29/06	500 HR	500 HR	No			No
No Action Required	SODIUM IS REPORTABLE. ALL WEAR METALS ARE ACCEPTABLE. SODIUM (SALT) ALONE MAY BE FROM SOME TYPE OF CLEANING SOAP. CONTINUE SAMPLING AT THE NORMAL INTERVAL.							
D390-36080-1038	3/20/06	3/21/06	234 HR	234 HR	Unknown		L	Unknown
No Action Required	ALL READINGS ARE ACCEPTABLE.CONTINUE SAMPLING AT THE NORMAL INTERVAL.							
D390-35182-1031	5/31/05	7/1/05	1 HR	1 HR	Unknown		L	Unknown
No Action Required	NORMAL BREAK-IN WEAR. ALL READINGS ARE ACCEPTABLE.CONTINUE SAMPLING AT THE NORMAL INTERVAL. MORE				: NEEDED TO ESTABLISH A WEAR TREND.			

Wear Metals (ppm)	Al	Ca	Cr	Cu	Fe	Pb	Mg	Mo	Ni	P	K	Si	Na	Sn
D390-36241-0023	1	3126	1	34	22	3	360	6	0	1463	4	4	62	1
D390-36080-1038	0	2772	1	7	11	1	364	4		1350	5	6	42	0
D390-35182-1031	1	2323	0	2	5	1	293	3		1184	2	4	0	0

Oil Condition / Particle Count (ct/ml)	ST	OXI	NIT	SUL	W	A	F	PFC	V100	TBN
D390-36241-0023	23	30	10	28	N	N	N	0.65	11.3	
D390-36080-1038	50	86	7	11	N	N	N		10.7	7.3
D390-35182-1031	15	1	0	0	N	N	N		11.2	

Ag = Silver, Al = Aluminum, B = Boron, Ca = Calcium, Cr = Chromium, Cu = Copper, Fe = Iron, P = Phosphorus, K = Potassium, Mg = Magnesium, Mo = Molybdenum, Na = Sodium, Ni = Nickel, Pb = Lead, Si = Silicon, Sn = Tin, V = Vanadium, Zn = Zinc, A = Antifreeze, F = Fuel, W = Water, P = Positive, N = Negative, T = Trace, E = Excessive, NIT = Nitration, OXI = Oxidation, ST = Soot, SUL = Sulfation, ISO = ISO Rating, PQI = Particle Quantifying index , NaW = Salt Water, FL Pt = Flash Point, TAN = Total Acid Number, TBN = Total Base Number, H2O = Karl Fisher result, V100 = Viscosity@100C, V40 = Viscosity@40C

Notice: This analysis is intended as an aid in predicting mechanical wear. No guarantee, expressed or implied, is made against failure of this piece of equipment or a component thereof.

In the early planning stage of the project, one major concern regarding the use of B-100 was injector coking. According to the National BioDiesel Board, fuel injector coking can occur as a result of fuel that is of a higher viscosity that is allowed under ASTM D975 or ASTM D6752 resulting in poor fuel atomization and fuel degradation[2]. Because of such concern, Caterpillar removed several of the injectors at 500-hours runtime and other injectors at 1007-hours runtime and performed an injector analysis on their performance.

[2] *Biodiesel Handling and Use Guidelines*, 2006 (U.S. Department of Energy, Energy Efficiency and Renewable Energy). (Publication with no author given)

Injector Analysis after 500 Hours

Fuel Systems Test

Report No: 075-010807

Failure Date:	N/A	**Date Received:**	09/11/2006
Product:	EI800B	**Engine Model:**	3516
Part#	2501314	**Eng. SN:**	
Miles/Hrs:		**Completion Date:**	01/08/07
RMA#:			
Quantity:	2		
Injector SN(s):	642048	642049	
Customer Complaint:	General inspection of injectors after 500 hrs engine testing with 100% biodiesel		

Return Type:

[ ] Warranty
[X] Special

Performance Results:

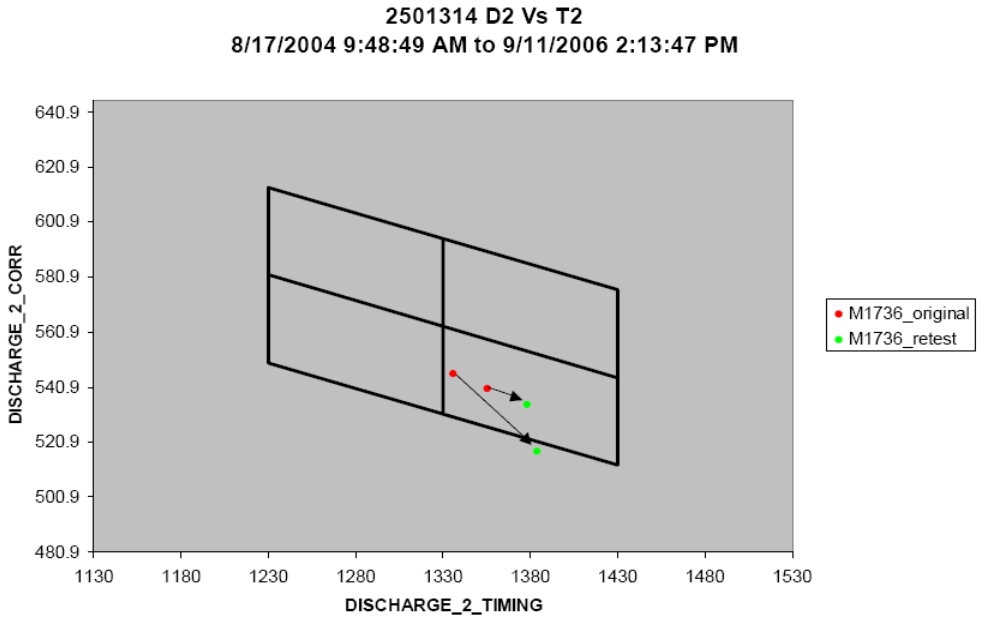


Figure 1. *Performance plot for rated test point*

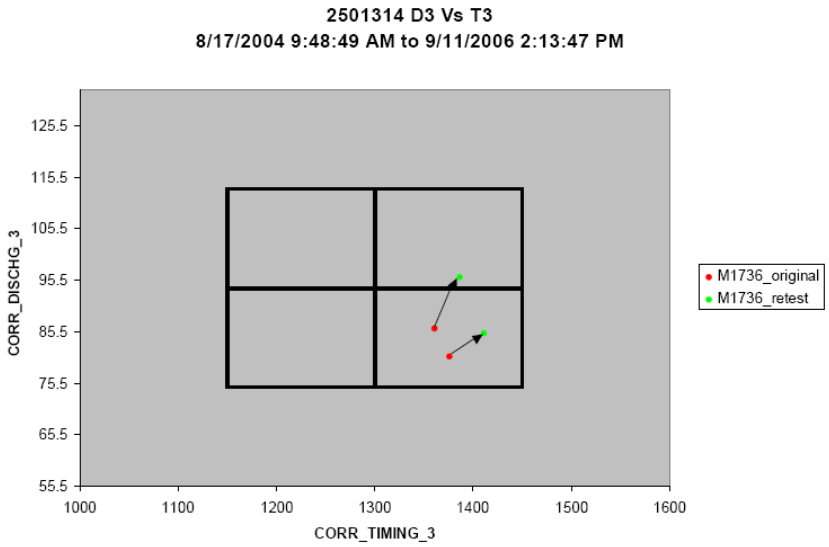


Figure 2. *Performance plot for idle test point*

Two injectors were sent to Pontiac for verifying their performance after 500 hrs with bio-diesel. As shown above in the performance plots, Injectors performance is not significantly different from its original performance. Both the injectors were found to be low on delivery and timing. This small variation might be due to some debris clogged in the valve or the nozzle assembly. One of the injectors (S/n 642048) passed the performance test on retesting and another (S/n 642049) failed marginally for lower rated delivery only (D2 Vs T2 relationship).

Table 1. *Percentage decrease in the Rated delivery*

S/N	% dec in rated delivery
642048	1.0
642049	5.2

As shown in Table 1 there was only 1% decrease in the rated delivery for injector with S/n 642048, which passed the test and there was 5.2% decrease in the rated delivery for injector with S/n 642049, which failed the test marginally but this is not a significant change.

Inspection:

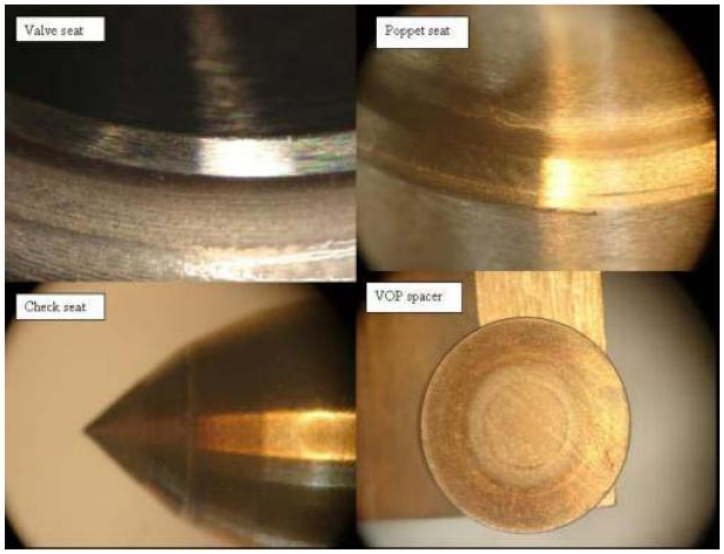


Figure 3. *Parts torn down and inspected for S/n 642048*

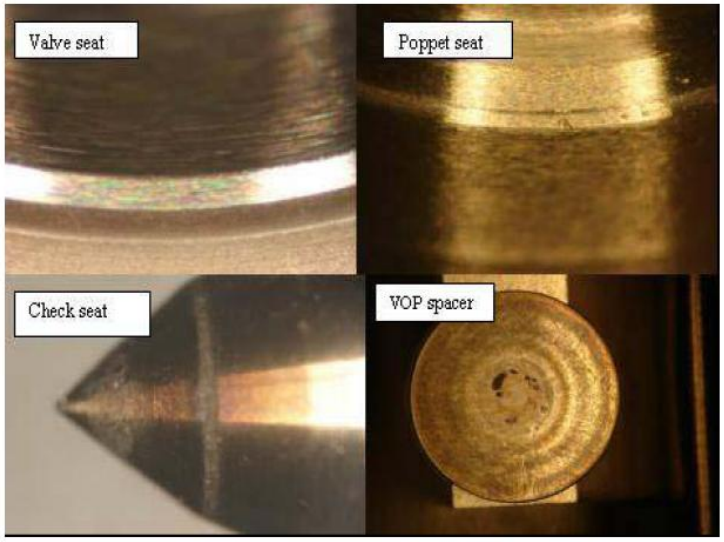


Figure 4. *Parts torn down and inspected for S/n 642049*

All the injector parts were inspected under magnification and as shown in the figure above none of the parts had any signs of cavitation or unusual wear.

Fuel Systems Test

Report No: 075-010807

Summary

Two injectors were submitted for general inspection after 500 hrs on engine with 100% biodiesel. Retest data is not significantly different from the original test data. One injector passed the performance test and one failed marginally for lower rated delivery as shown in the Figure 1 (D2 Vs T2 relationship). Rated as well as idle deliveries were on the lower side, which might be due to the flow restriction in the tips or bench movement.

Analyzed By: Jaspal Rawat/Steve Wehri

Ext.: 7-244-5852/5446

All components will be cored two weeks after the completion date unless otherwise noted!

Injector Analysis after 1007 Hours of Operations

Fuel Systems Test

Report No: 076-011107

Failure Date:	N/A	**Date Received:**	01/10/2007
Product:	EI800B	**Engine Model:**	3516
Part#	2501314	**Eng. SN:**	
Miles/Hrs:		**Complétion Date:**	01/08/07
RMA#:			
Quantity:	2		
Injector SN(s):	642053	642058	
Customer Complaint:	General inspection of injectors after 1000 hrs engine testing with 100% biodiesel		

Return Type:

[ ] Warranty
[X] Special

Performance Results:

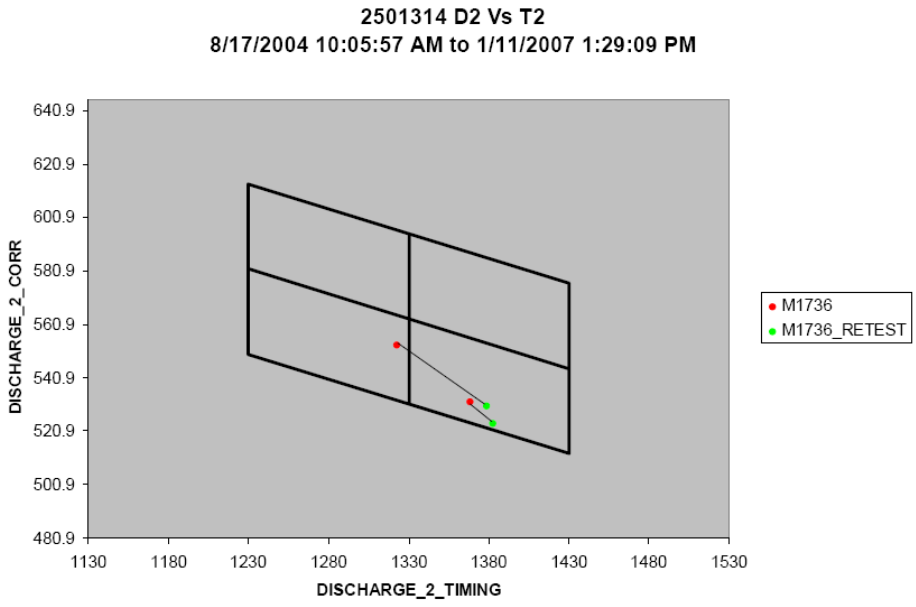


Figure 1. *Performance plot for rated test point*

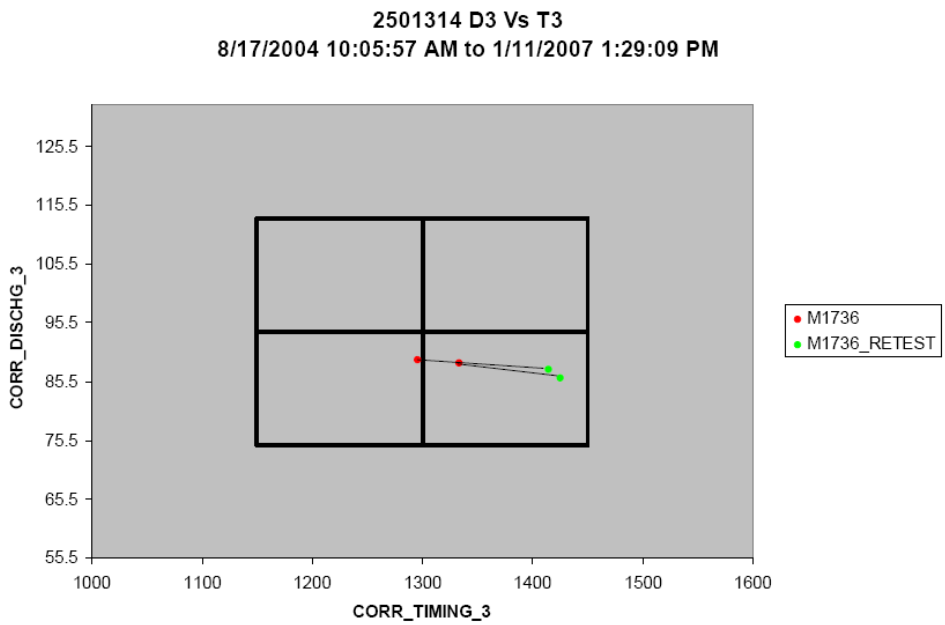


Figure 2. *Performance plot for idle test point*

Table1. *Percentage decrease in the rated delivery*

S/N	% dec in rated delivery	Leakage (150MPa max)
642053	4.1	179.03
642058	1.5	122.12

Two injectors were sent to Pontiac for verifying their performance after 1000 hrs with bio-diesel. As shown above in the performance plots, Injectors performance is not significantly different from its original performance. Both the injectors were found to be low on delivery and timing. This small variation might be due to some debris clogged in the valve or the nozzle assembly. As shown in Table 1, one of the injectors (S/n 642053) passed the performance test on retesting and another (S/n 642058) failed for leak, which is marginally out of the limit and which could be a bench error.

Inspection:

All the injector parts were inspected thoroughly under magnification and as show in the figure below, there is no sign of cavitation or unusual wear on the critical injector components.

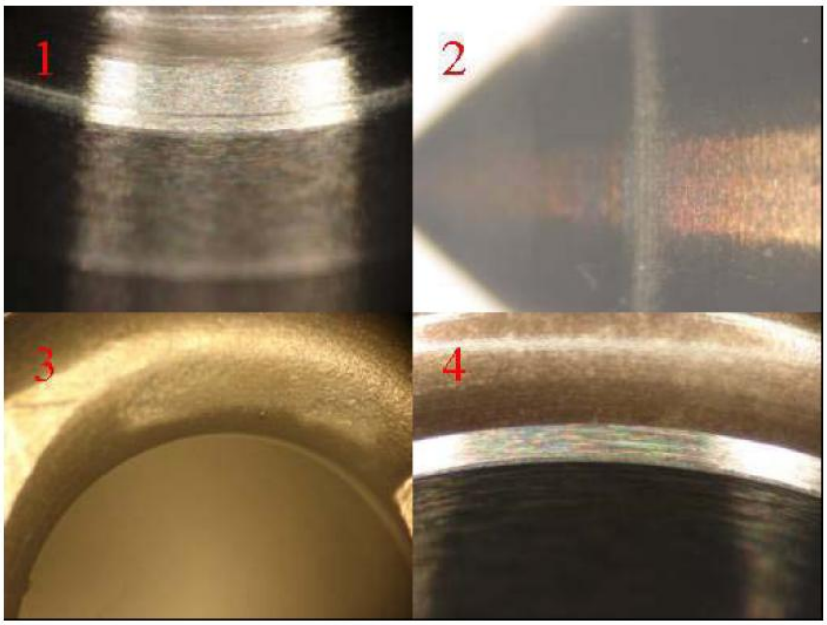


Figure 3. *1) Poppet seat 2) Check seat 3) Nozzle spring 4) Valve seat in 642058*

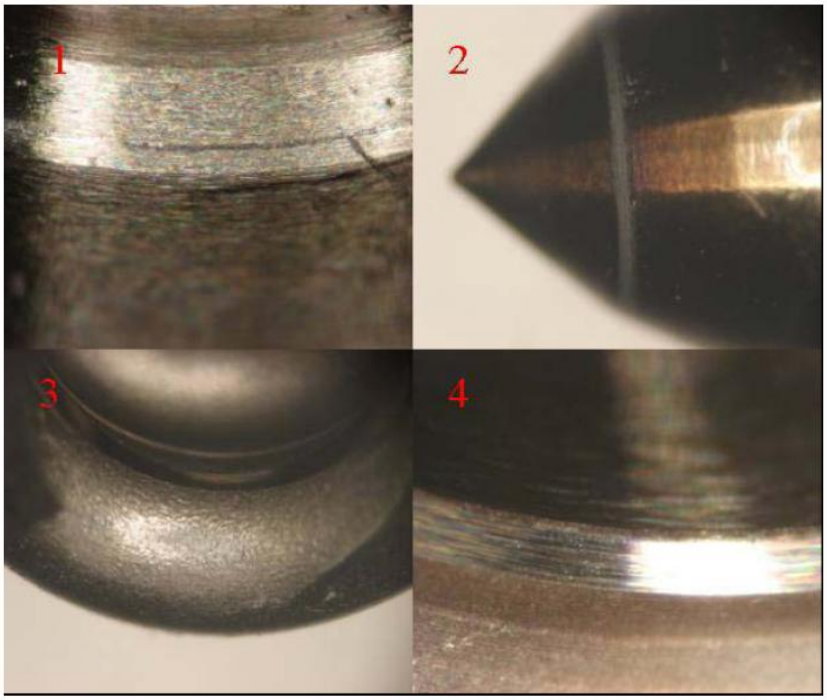


Figure 4. *1) Poppet seat 2) Check seat 3) Nozzle spring 4) Valve seat in 642053*

Fuel Systems Test

Report No: 076-011107

Summary

Two injectors were submitted for general inspection after 1000 hrs of operation with 100% biodiesel in the engine. One injector passed the performance test on retesting and one failed marginally for leakage. Performance results are not significantly different from the original test data. Rated as well as idle deliveries and timing are on the lower side, which might be because of the flow restriction in tips due to debris. This was also seen in the 500hr test returned injectors for inspection with 100% biodiesel (See report 075-010807).

Analyzed By: Jaspal Rawat/Steve Wehri

Ext.: 7-244-5852/5446

All components will be cored two weeks after the completion date unless otherwise noted!

Budget:

Description	Preliminary Budget
Generator - Caterpillar	$ 505,850
Motor Testing	$ 110,900
Fuel Tank	$ 35,000
Fuel - Biodiesel	$ 187,500
Transportation Cost	$ 10,704
Catalyst	$ 324,209
Payroll	$ 100,921
Fringe Benefits	$ 44,110
Attorney	$ 16,000
Electrical Engineering	$ 10,000
Energy Consultant & Misc.	$ 10,000
Transformer /equip	$ 21,000
Environmental Consultant	$ 4,300
Crane Work	$ 2,000
Testing of Emissions	$ 45,000
Travel	$ 3,000
TOTALS	$ 1,430,494

Additional Notes:

On November 28, 2006, SECOR International Inc. prepared an Emissions measurements Report for McMinnville Electric System as detailed in Construction Permit No. 957279F, issued by the Tennessee Department of Environment and Conservation (TDEC), Division of Air Pollution Control (APC). The Permit specified, in Condition 15 of the construction permit, that McMinnville Electric System must conduct an emissions performance test to demonstrate compliance with the NOx emissions limit. Testing was performed in accordance with test methods and procedures detailed in 40 CFR 60, Appendix A. The report from SECOR in its entirety is hereby incorporated into this Report as Attachment “F”.

References:

Mitchell, L. and DeCicco, S., 2007, EMx Prototype Testing on a Caterpillar 3616 TA Stationary Internal Combustion Engine Running on Various Blends of Petroleum Diesel and Soybean-Based BioDiesel. *Working paper, EmeraChem, LLC.,* Research Notes (Working paper)

McMinnville BioDiesel Test, 2007 (Publication with no author given)

Czernichowski, A., Czernichowski, M., Wesolowska, K., 2006, Generation of 1 kg/h of Hydrogen from Soybean BioDiesel (*White paper prepared for the American Chemical Society 232nd National Meeting and Exposition*)

Czernichowski, A., Czernichowski, M., 2006, Further development of Plasma sources: the GlidArc-III. (*White paper prepared by ECP – GlidArc Technologies, La Ferté St Aubin, France*)

Czernichowski, A., Czernichowski, M., Czernichowski, P. Wesolowska, K., 2006, Hydrogen or Syngas Generation using Plasma Technology. (*White paper from the Topsoe Catalysis Forum 2006, Future Hydrogen Generation and Application*)

Rawat, J., Wehri, S., Report No: 075-010807, Fuel System Test (*Caterpillar Fuel System*). (Internal Report)

Rawat, J., Wehri, S., Report No: 075-011107, Fuel System Test (*Caterpillar Fuel System*). (Internal Report)

Ewing, G., 2006, Emissions Measurement Report for McMinnville Electric System. *(Compliance Report prepared by SECOR International Inc.)*

Attachment "A"

(The following report, which pertains solely to BioDiesel fuel test results, was commissioned by the Tennessee Valley Authority for McMinnville Electric System and is therefore incorporated and is made part of this Final Report as submitted. The author is Jim Hedman with the Minnesota Department of Commerce, Weights and Measures Division, Petroleum Laboratory Services)

Weights and Measures Division
Petroleum Laboratory Services
2277 Highway 36
Roseville, MN 55113-3800

Jim Hedman, Metrologist

Direct: 651-296-2990
Cell: 651-269-6808
Lab: 651-215-5842
Fax: 651-639-4014

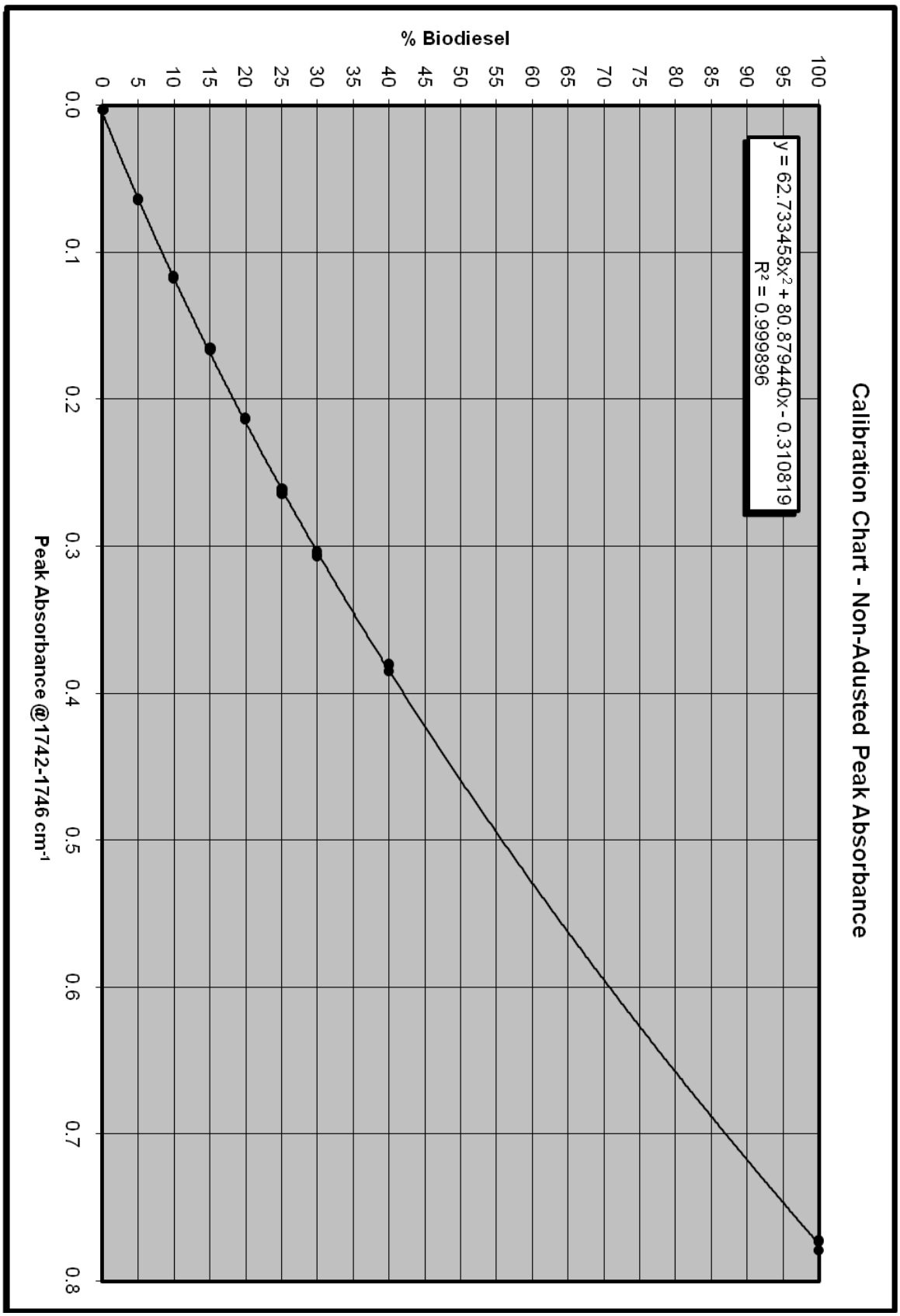
E-Mail: Jim.Hedman@state.mn.us

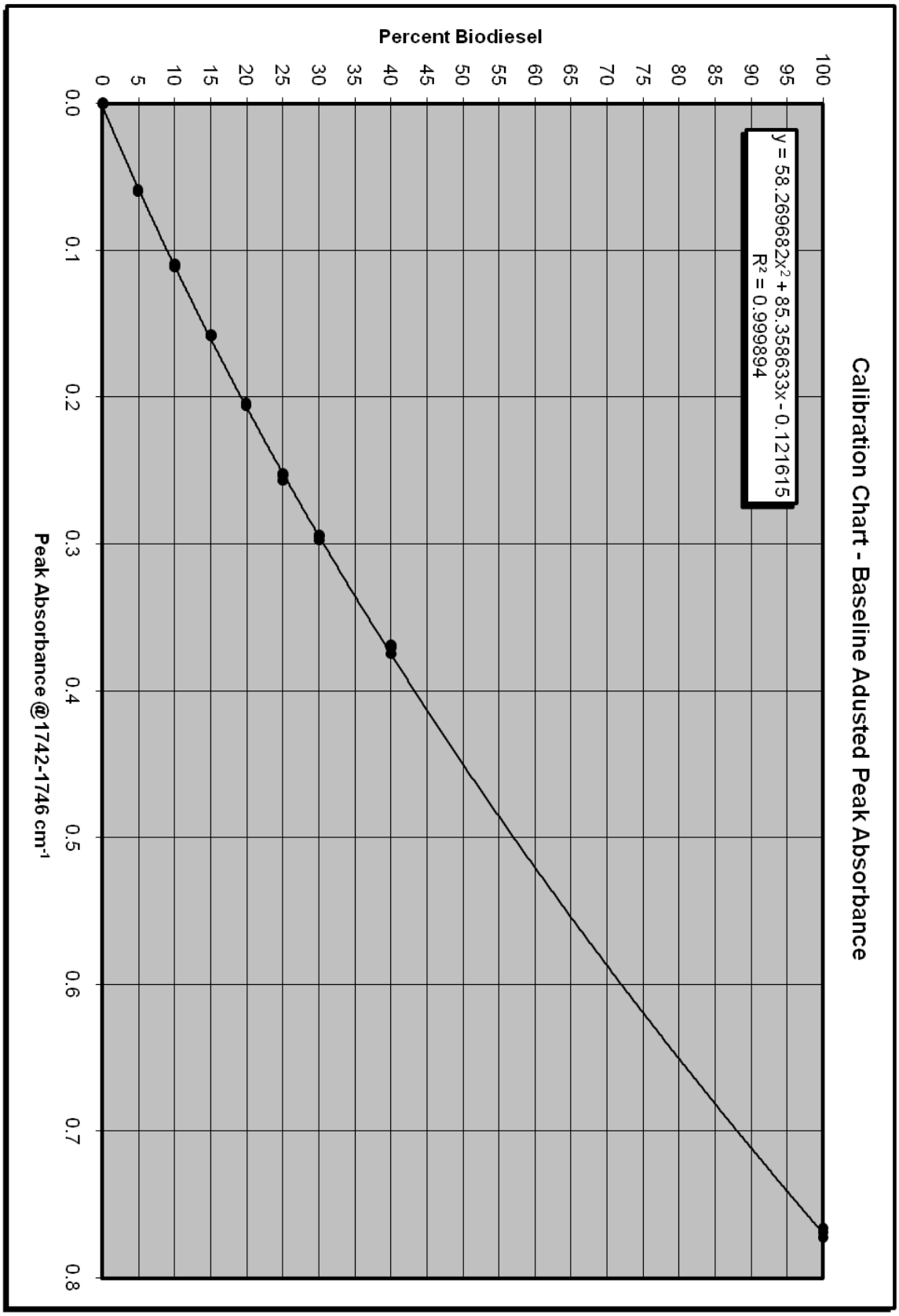
Results for TVA samples shipped 11/17/05

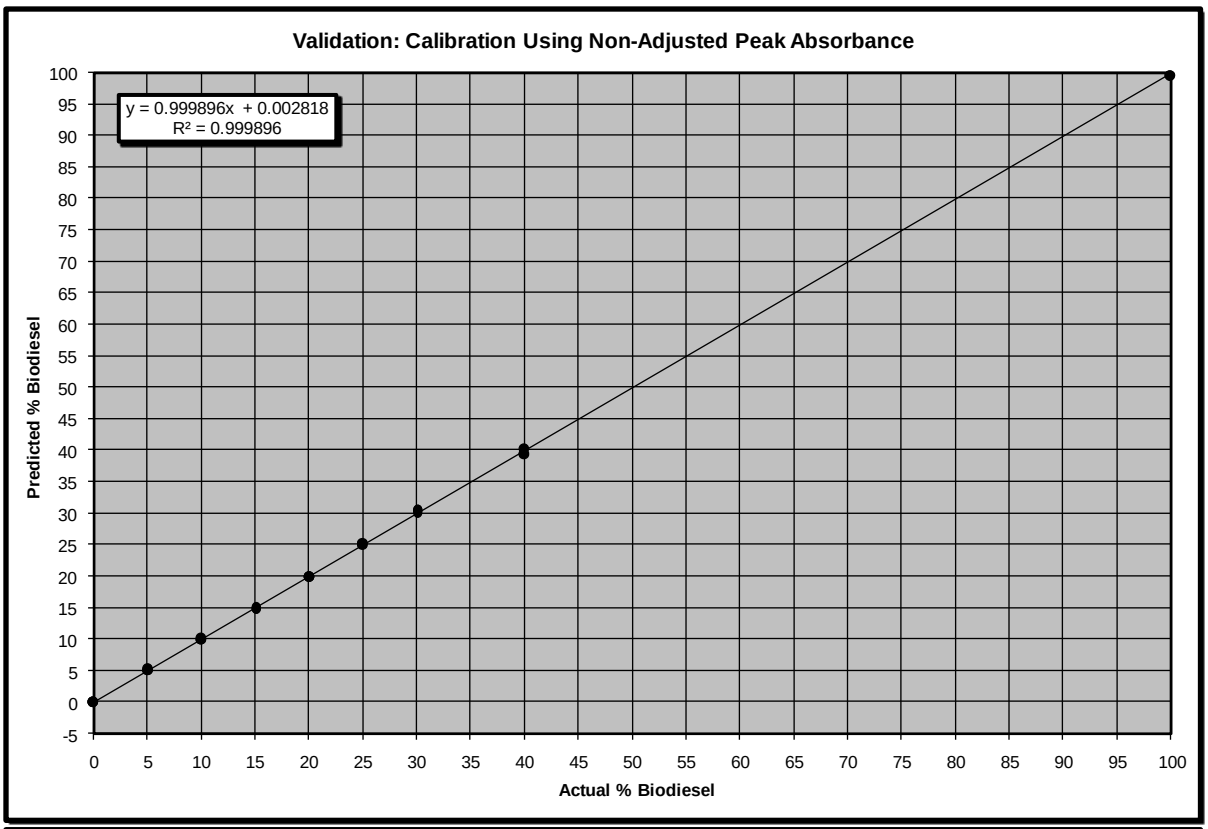
Trace File Name	Sample I.D.	Client I.D.	Peak Absorb.	Wave Number	% Blend Predict	Baseline Absorb.	Adjusted Absorb.	% Blend Predict
tva-unk aa_pm_1.spc	tva-unk a	A	0.355465	1745.0	36.37	0.005998	0.349467	36.82
tva-unk aa_pm_2.spc	tva-unk a	A	0.356975	1745.0	36.56	0.006157	0.350817	37.00
tva-unk aa_pm_3.spc	tva-unk a	A	0.356563	1745.0	36.50	0.005157	0.351406	37.07
Sample "A"				**Average**	**36.47**		**Average**	**36.96**
				Std. Dev.	**0.10**		**Std. Dev.**	**0.13**
				Uncertainty	**0.27**		**Uncertainty**	**0.35**
tva-unk ba_pm_1.spc	tva-unk b	B	0.027395	1747.4	1.95	0.005124	0.022272	1.81
tva-unk ba_pm_2.spc	tva-unk b	B	0.027862	1747.2	1.99	0.004331	0.023531	1.92
tva-unk ba_pm_3.spc	tva-unk b	B	0.027143	1747.3	1.93	0.003951	0.023191	1.89
Sample "B"				**Average**	**1.96**		**Average**	**1.87**
				Std. Dev.	**0.03**		**Std. Dev.**	**0.06**
				Uncertainty	**0.09**		**Uncertainty**	**0.16**
tva-unk ca_pm_1.spc	tva-unk c	C	0.216798	1746.1	20.17	0.004015	0.212783	20.68
tva-unk ca_pm_2.spc	tva-unk c	C	0.218639	1746.1	20.37	0.004519	0.214120	20.83
tva-unk ca_pm_3.spc	tva-unk c	C	0.218284	1746.1	20.33	0.004780	0.213504	20.76
Sample "C"				**Average**	**20.29**		**Average**	**20.76**
				Std. Dev.	**0.11**		**Std. Dev.**	**0.07**
				Uncertainty	**0.29**		**Uncertainty**	**0.14**
tva-unk da_pm_1.spc	tva-unk d	D	0.058266	1746.9	4.61	0.001905	0.056362	4.87
tva-unk da_pm_2.spc	tva-unk d	D	0.058221	1746.9	4.61	0.002322	0.055899	4.83
tva-unk da_pm_3.spc	tva-unk d	D	0.059020	1746.9	4.68	0.002947	0.056073	4.85
Sample "D"				**Average**	**4.64**		**Average**	**4.85**
				Std. Dev.	**0.04**		**Std. Dev.**	**0.02**
				Uncertainty	**0.11**		**Uncertainty**	**0.06**
tva-unk ea_pm_1.spc	tva-unk e	E	0.754085	1741.8	96.35	0.007425	0.746660	96.10
tva-unk ea_pm_2.spc	tva-unk e	E	0.760908	1741.8	97.55	0.007996	0.752911	97.18
tva-unk ea_pm_3.spc	tva-unk e	E	0.763620	1741.8	98.03	0.008349	0.755271	97.59
Sample "E"				**Average**	**97.31**		**Average**	**96.95**
				Std. Dev.	**0.87**		**Std. Dev.**	**0.77**
				Uncertainty	**2.40**		**Uncertainty**	**2.13**

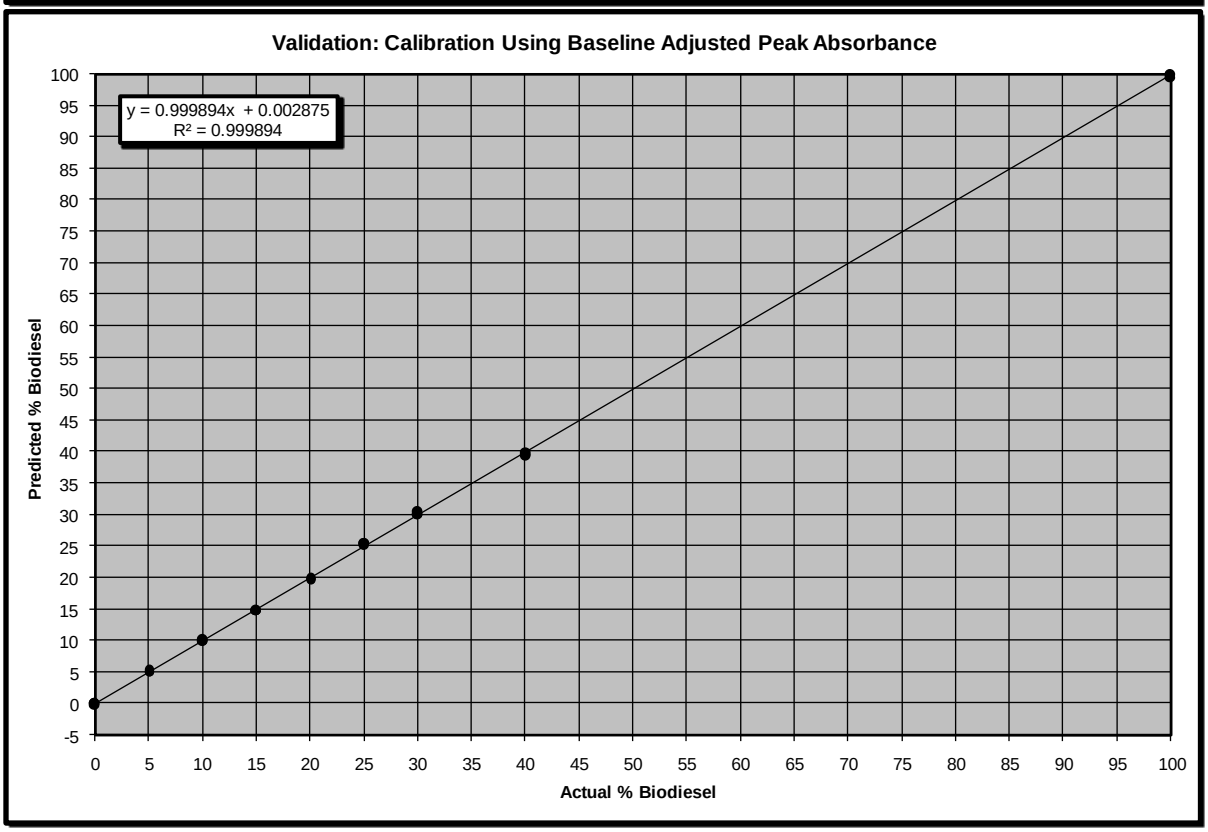
TVA Biodiesel Blend Standards and FTIR Calibration Data From Materials Shipped 11/17/05

Trace File Name	Sample I.D.	Percent Biodiesel	Raw Peak Absorb.	Wave Number	Self Predict	Predict Error	Baseline Absorb.	Adjusted Absorb.	Self Predict	Predict Error	Predict Improved
tva-b000b_pm_1.spc	tva-b000	0	0.003086	1746.6	-0.06	-0.06	0.003209	-0.000123	-0.13	-0.13	-0.07
tva-b000b_pm_2.spc	tva-b000	0	0.002983	1746.6	-0.07	-0.07	0.002952	0.000031	-0.12	-0.12	-0.05
tva-b000b_pm_3.spc	tva-b000	0	0.002986	1746.6	-0.07	-0.07	0.002618	0.000368	-0.09	-0.09	-0.02
tva-b005a_pm_1.spc	tva-b105	5	0.064853	1746.9	5.20	0.20	0.004799	0.060054	5.21	0.21	-0.02
tva-b005a_pm_2.spc	tva-b105	5	0.064142	1746.9	5.14	0.14	0.004799	0.059343	5.15	0.15	-0.01
tva-b005a_pm_3.spc	tva-b105	5	0.063645	1746.9	5.09	0.09	0.004644	0.059001	5.12	0.12	-0.03
tva-b010b_pm_1.spc	tva-b010	10	0.117970	1746.8	10.10	0.10	0.006551	0.111419	10.11	0.11	-0.01
tva-b010b_pm_2.spc	tva-b010	10	0.116328	1746.8	9.95	-0.05	0.005891	0.110437	10.02	0.02	0.04
tva-b010b_pm_3.spc	tva-b010	10	0.116928	1746.8	10.00	0.00	0.007125	0.109803	9.95	-0.05	-0.04
tva-b015b_pm_1.spc	tva-b015	15	0.166992	1746.7	14.94	-0.06	0.008262	0.158730	14.90	-0.10	-0.05
tva-b015b_pm_2.spc	tva-b015	15	0.165446	1746.6	14.79	-0.21	0.008212	0.157234	14.74	-0.26	-0.05
tva-b015b_pm_3.spc	tva-b015	15	0.164639	1746.6	14.71	-0.29	0.006138	0.158500	14.87	-0.13	0.17
tva-b020b_pm_1.spc	tva-b020	20	0.213240	1746.5	19.79	-0.21	0.008997	0.204243	19.74	-0.26	-0.05
tva-b020b_pm_2.spc	tva-b020	20	0.213895	1746.5	19.86	-0.14	0.008115	0.205779	19.91	-0.09	0.05
tva-b020b_pm_3.spc	tva-b020	20	0.213834	1746.5	19.85	-0.15	0.008531	0.205303	19.86	-0.14	0.01
tva-b025b_pm_1.spc	tva-b025	25	0.260551	1746.3	25.02	0.02	0.008064	0.252487	25.14	0.14	-0.12
tva-b025b_pm_2.spc	tva-b025	25	0.264171	1746.2	25.43	0.43	0.007338	0.256832	25.64	0.64	-0.21
tva-b025b_pm_3.spc	tva-b025	25	0.262627	1746.2	25.26	0.26	0.008695	0.253932	25.31	0.31	-0.05
tva-b030b_pm_1.spc	tva-b030	30	0.307030	1746.0	30.44	0.44	0.012069	0.294961	30.13	0.13	0.31
tva-b030b_pm_2.spc	tva-b030	30	0.306407	1746.0	30.36	0.36	0.009125	0.297282	30.40	0.40	-0.04
tva-b030b_pm_3.spc	tva-b030	30	0.303844	1745.9	30.06	0.06	0.009448	0.294397	30.06	0.06	0.00
tva-b040b_pm_1.spc	tva-b040	40	0.384774	1745.1	40.10	0.10	0.009931	0.374842	40.06	0.06	0.04
tva-b040b_pm_2.spc	tva-b040	40	0.381276	1745.1	39.65	-0.35	0.010077	0.371199	39.59	-0.41	-0.05
tva-b040b_pm_3.spc	tva-b040	40	0.379760	1745.1	39.45	-0.55	0.010405	0.369355	39.36	-0.64	-0.10
tva-b100b_pm_1.spc	tva-b100	100	0.773463	1741.9	99.78	-0.22	0.004875	0.768588	99.91	-0.09	0.13
tva-b100b_pm_2.spc	tva-b100	100	0.779026	1741.9	100.77	0.77	0.006238	0.772787	100.64	0.64	0.13
tva-b100b_pm_3.spc	tva-b100	100	0.771793	1742.0	99.48	-0.52	0.005441	0.766352	99.51	-0.49	0.04


Calibration Chart - Non-Adusted Peak Absorbance
% Biodiesel
Peak Absorbance @1742-1746 cm-1
y = 62.733458x2 + 80.879440x - 0.310819
R² = 0.999896
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8


Calibration Chart - Baseline Adusted Peak Absorbance
Percent Biodiesel
Peak Absorbance @1742-1746 cm-1
y = 58.269682x2 + 85.358633x - 0.121615
R² = 0.999894
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8


Validation: Calibration Using Non-Adjusted Peak Absorbance
y = 0.999896x + 0.002818
R² = 0.999896
Predicted % Biodiesel
Actual % Biodiesel
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100


Validation: Calibration Using Baseline Adjusted Peak Absorbance
y = 0.999894x + 0.002875
R² = 0.999894
Predicted % Biodiesel
Actual % Biodiesel
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100

December 20, 2005

Tennessee Valley Authority
Attn: Ralph Boroughs
1110 Market Street, SP-5D
Chattanooga, TN 37402

Mr. Boroughs:

My apologies for the delay in getting results back to you on the samples you shipped November 17th for biodiesel blend determinations. However, from late fall through this early winter we have be swamped with priority investigative and oversight work on a number of pressing issues such as water in gasoline, gasoline octane misrepresentation, methanol in biodiesel, and a number of varied filter clogging issues involving biodiesel blended diesel fuel. As luck would have it, the delay was somewhat fortuitous because of a contamination problem I found with the B100 biodiesel sample you submitted, that probably would not have been recognized had I not had to deal with a biodiesel flashpoint issue that materialized some weeks ago. I will deal with the contamination problem shortly, but for now I turn to the biodiesel blend determinations you requested.

Results were as follows:

- **Sample A:** **36.96 Volume %**
- **Sample B:** **1.87 Volume %**
- **Sample C:** **20.76 Volume %**
- **Sample D:** **4.85 Volume %**
- **Sample E:** **96.95 Volume %**

Full validation of the quadratic regression calibration protocol employed has yet to be accomplished, but past work indicates uncertainties should range from about 0.2 vol.% up to B5, under 0.8 vol. % through B20, under 1.5 vol% through B40 and under 3 vol. % at B100. Details of the calibration procedure can be reviewed by viewing the companion Excel workbook file: *TVA Biodiesel Blend Calibration.xls*. Please note that data for a B50 standard was discarded from the calibration set as an "outlier".

I now return to the unanticipated problem with the biodiesel blend-stock submitted for use as a standard:

There appeared to be something a bit unusual about the B100 trace file so I compared it, using an overlay plot, with a pair of soy methyl ester sample retains from different plants. It became immediately obvious that there was unusually high absorbance in the spectral trace for your

B100 at about 1030 cm^{-1}. This would correlate with methanol contamination. I realized this because, as luck would have it, I have recently undertaken a methanol-in-biodiesel quantification project, based on FTIR spectroscopic analysis. Locally, some biodiesel flash point issues have materialized. As you are probably aware, the ASTM D6851 biodiesel specification sets a very high flash point criterion (130° C), as the test is employed as a surrogate for a direct methanol test. However, there are reproducibility problems with flash point determination at such high temperatures and also there are issues with the appropriateness of the test as a methanol screen when sampling is undertaken down-stream from a production plant.

Therefore, I have recently initiated a project to develop a direct test for methanol contamination of biodiesel by FTIR. The project is still in the pilot phase, but I have acquired a few scans of methanol contamination standards for demonstration purposes. I compared your TVA submitted B100 sample, using an overlay plot, with B100 samples spiked with 5% and 1% methanol by volume. Also included was the stock sample used for the methanol spikes. This overlay is depicted in Figure 1.

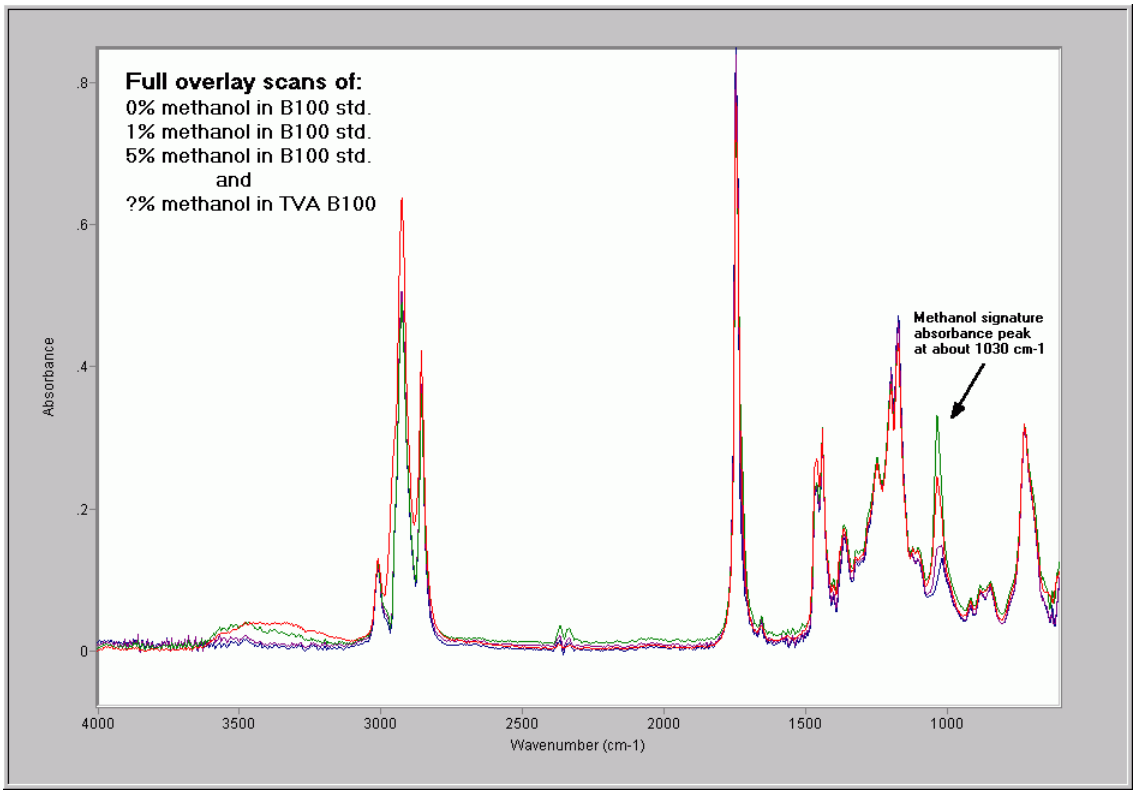


Figure 1. Overlay plot of spectral traces for TVA submitted sample compared with 0%, 1% and 5% methanol spiked B100 "standards". The "signature" peak for methanol appears at about 1030 cm^{-1} and is very evident.

Next, in Figure 2, the region about wavenumber 1030 cm^{-1} is shown in a zoomed view to facilitate detailed comparison of the spectra.

Clearly, the peak absorbance for the TVA submitted sample lies about midway between the peak absorbencies for the 1% and 5% methanol spiked B100 standards. Therefore, it can be concluded that the TVA submitted sample contains roughly 3% methanol. A more precise estimate could be obtained by using additional interlaying standards, preferably employing them in a calibration protocol using regression or multivariate analysis. One potential problem in developing a low-level methanol in biodiesel calibration is the "native" biodiesel absorbance increase at about 1017 cm^{-1} wavenumber. The interference of the biodiesel peak is already evident in the 1% methanol trace. However, the methanol contamination in the TVA submitted B100 is far above the trace amounts anticipated in a method that will hopefully be sensitive to concentrations down to 0.2% or lower.

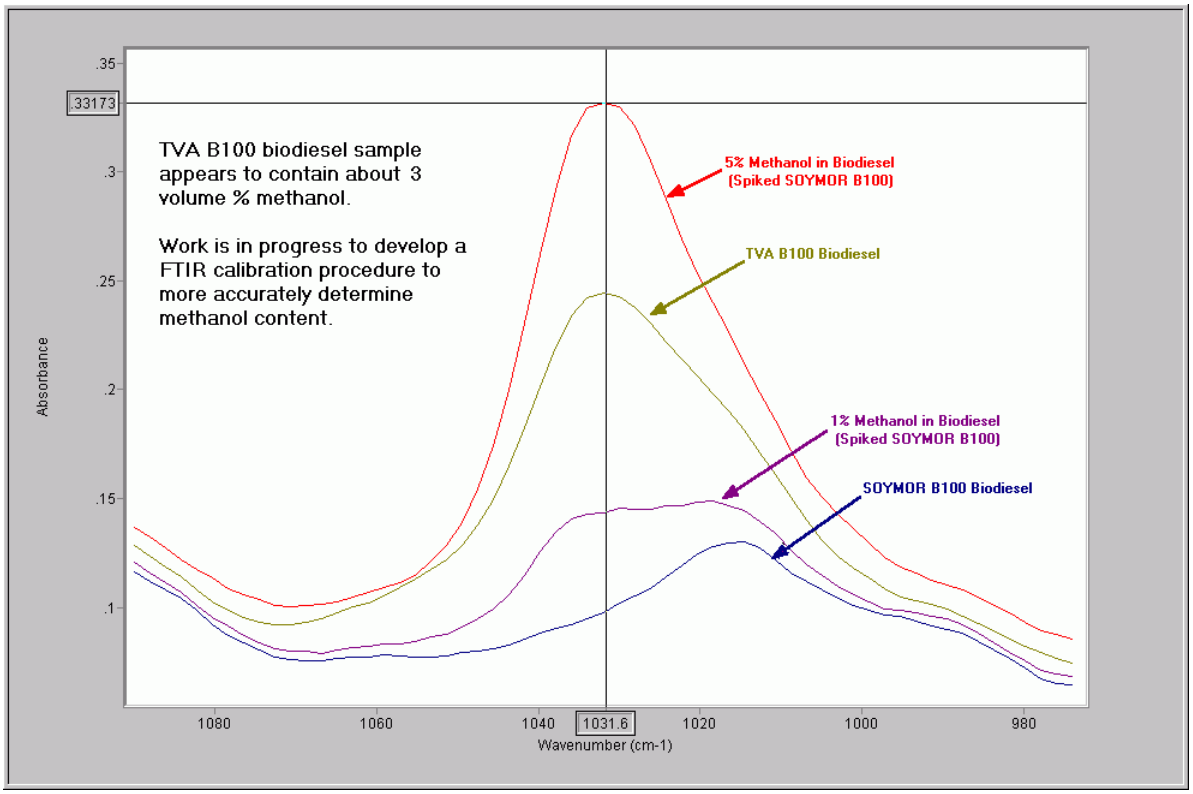


Figure 2. Zoomed "methanol signature region" overlay plot of spectral traces for TVA submitted sample compared with 0%, 1% and 5% methanol spiked B100 "standards". The contamination in the TVA sample appears to be about 3 vol. %.

I was rather surprised, if not shocked, to see such a high level of methanol contamination in the B100 you supplied. The anticipated methanol level associated with the ASTM D6851 flash point specification of 130° C is only 0.2% - with a view to harmonization with the European biodiesel specification.

It should also be noted that a "methanol signature" was clearly evident in the TVA samples identified as A, C and E. These were the three highest determined biodiesel blend levels. Assuming that the B100 indeed contains 3% methanol, at B5 the methanol concentration would be reduced to 3 x .05 = 0.15 vol.%, which is probably near the limit of detection for this sort of analysis (time and effort will tell).

Again my apologies for the delay in submitting this report, but had I made the blend determinations in a very timely manner, the methanol contamination issue would most likely have been overlooked. See companion paper (in zipped file) *Biodiesel - MeOH Detection (051129a).pdf* for more information about the methanol detection method project that led to the discovery of the methanol issue with the samples you submitted.

Please feel free to write or call me at **651-296-2990** with any questions, concerns or commentary.

Sincerely,

Jim Hedman, Metrologist

Attachment "B"

(The following report, which pertains solely to the Prototype SCONOX NOx emissions reduction system which as designed and built for this Project by EmeraChem, LLC., was commissioned by McMinnville Electric System and is therefore incorporated and is made part of this Final Report as submitted. The authors are Steve DeCicco and Lisa Mitchell, EmeraChem, LLC)

Introduction

Demonstration Goals

The ultimate goal of MES' demonstration program is to demonstrate the ability to generate electricity on 100% renewable fuel source, while maintaining emissions at or lower than non-renewable sources. This would allow McMinnville Electric System to qualify for TVA's "Green Power Switch" program.

EmeraChem's goal is to demonstrate clean emissions on a large stationary IC engine across all liquid fuel blends. Furthermore, EmeraChem hopes to develop a commercial product for stationary diesel engine applications.

Background

EmeraChem's NOx adsorber catalysts have been demonstrated on bench scale reactors and on diesel engine exhaust. Long term data on EMx™ performance exists from commercial applications on 5 – 50 MW natural-gas and dual fuel fired turbines demonstrating NOx emissions less than 1 ppm and virtually undetectable CO and HC levels. Long term data on EMx™ on diesel engines is limited to studies on small, 5 – 50 kW, diesel engine generator-set test platforms, demonstrating more than 90% removal of NOx, CO, and HC. This test represents the verification of the performance of the catalyst on the exhaust from a larger scale, 2 MW, stationary diesel engine.

Experiment Design

Engine Test Platform

The engine generator-set is Caterpillar 3516B TA diesel engine (see **Figure II-1**) coupled to a Caterpillar SR4B generator and has a 4.46 g/bhp-hr NOx emission rating. The exhaust flow is assumed to be 5,636 scfm (wet, at 32 ˚ F and 29.98" Hg) as predicted by Caterpillar. The gen-set is attached to the electric grid, and is at full load at all times. The engine was run for approximately 16 hours prior to the start of testing to break in the engine and ensure sealing of all exhaust system components.

Figure II-1

Fuel and Lubricants

Various blends of ultra-low sulfur diesel (ULSD) and 100% soybean based biodiesel (B100) fuels were used to fuel both the engine and the plasma reformer for regen gas generation. The fuels were mixed manually in the fuel day tank. The ratios of ULSD to B100 fuel were chosen to represent various fuel blends commercially available. The sulfur content of the ULSD was 15 ppm, and 0 ppm for the biodiesel.

Testing Protocol

Prior to the emissions testing, the plasma reformer operation was optimized to develop a start-up procedure and confirm sufficient hydrogen production. The catalyst modules were not installed prior to the initial day of ULSD fuel testing.

The catalyst was operated with a cycle time of 4 minutes for early testing, and revised to 3.5 minutes before B20 testing began.

After the 4-hour tests on each of the various fuel blends, the engine was run on B100 for the remainder of the testing. The catalyst was washed after each day of testing to eliminate the effects of sulfur accumulation from test to test.

Catalyst System

The catalyst system is a dual chamber reactor with inlet exhaust isolation valves controlling the direction of exhaust flow (see **Figure II-2**). The exhaust isolation valves used a common actuator and were linked together to assure that the engine exhaust would always have an open flow path and never be restricted. Regeneration was accomplished by generating a regen gas from the parent fuel using a plasma reformer. The regen gas was injected in a "forward-flow" geometry (the regen gas flowed in the exhaust flow direction).

Figure II-2

The catalyst system was mounted 20 ft from the gen-set exhaust as shown in **Figure II-3**; thus, allowing enough thermal loss in the un-insulated exhaust pipe to bring the catalyst operating temperature down to an operating temperature of 750 ° F. The gen-set was enclosed in a sound-reducing housing and catalyst system was installed outside with no

additional rain protection.

Catalysts

The catalyst (see **Figure II-4**) used for the test was standard EMx, utilizing K_2CO_3 sorber on a barium-alumina washcoat. The catalysts were on 200 cpsi cordierite substrates. Four rows of EMx catalyst were installed in each chamber, with two 18" x 42" x 6" modules per row. The total catalyst volume for each catalyst chamber was 21 ft^3. Sulfur management was handled by frequent washing of the catalyst, no ESx catalyst was installed.

Figure II-3

The EMx catalyst works by simultaneously oxidizing CO to CO_2, VOCs to CO_2 and H_2O, NO to NO_2, and then absorbing NO_2 onto its surface through the use of an alkaline metal solution absorber coating such as potassium carbonate. These reactions are shown below, and are referred to as the "Oxidation/Absorption Cycle".

$$CO + ½O_2 \rightarrow CO_2$$

$$C\,H_2O + O_2 \rightarrow CO_2 + H_2O$$

$$NO + ½O_2 \rightarrow NO_2$$

$$2NO_2 + K_2CO_3 \rightarrow CO_2 + KNO_2 + KNO_3$$

$$2NO_2 + Ba_2CO_3 \rightarrow CO_2 + BaNO_2 + BaNO_3$$

The small quantity of CO_2 in the above reactions exhausts up the stack. Note that during this cycle, the potassium carbonate coating quantitatively and chemically bonds and traps the nitrogen oxides to form potassium nitrites and nitrates, which are then present on the surface of the catalyst. Before the potassium

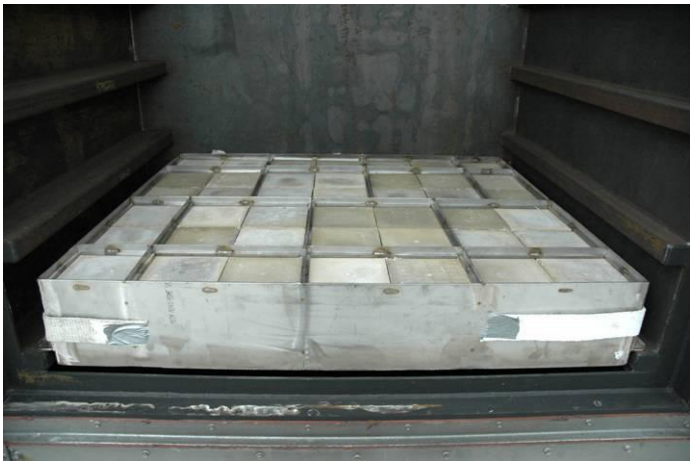


Figure II-4

carbonate on the surface of the catalyst becomes saturated with nitrogen oxides, the catalyst enters the regeneration cycle.

The regeneration of the EMx catalyst, one of the features that makes the system so unique, is accomplished by passing a reducing gas across the surface of the catalyst in the absence of oxygen. The reductants in the regeneration gas (hydrogen and carbon monoxide) react with nitrites and nitrates to form water, elemental nitrogen, and potassium hydroxide. Carbon dioxide in the engine exhaust reacts with potassium hydroxide to form potassium carbonate, which is the absorber coating that was on the surface of the catalyst before the oxidation/absorption cycle began. This cycle is referred to as the "Regeneration Cycle", and the relevant reaction is shown below.

$$KNO_2 + KNO_3 + 4H_2 + CO_2 \rightarrow K_2CO_3 + 4H_2O + N_2$$

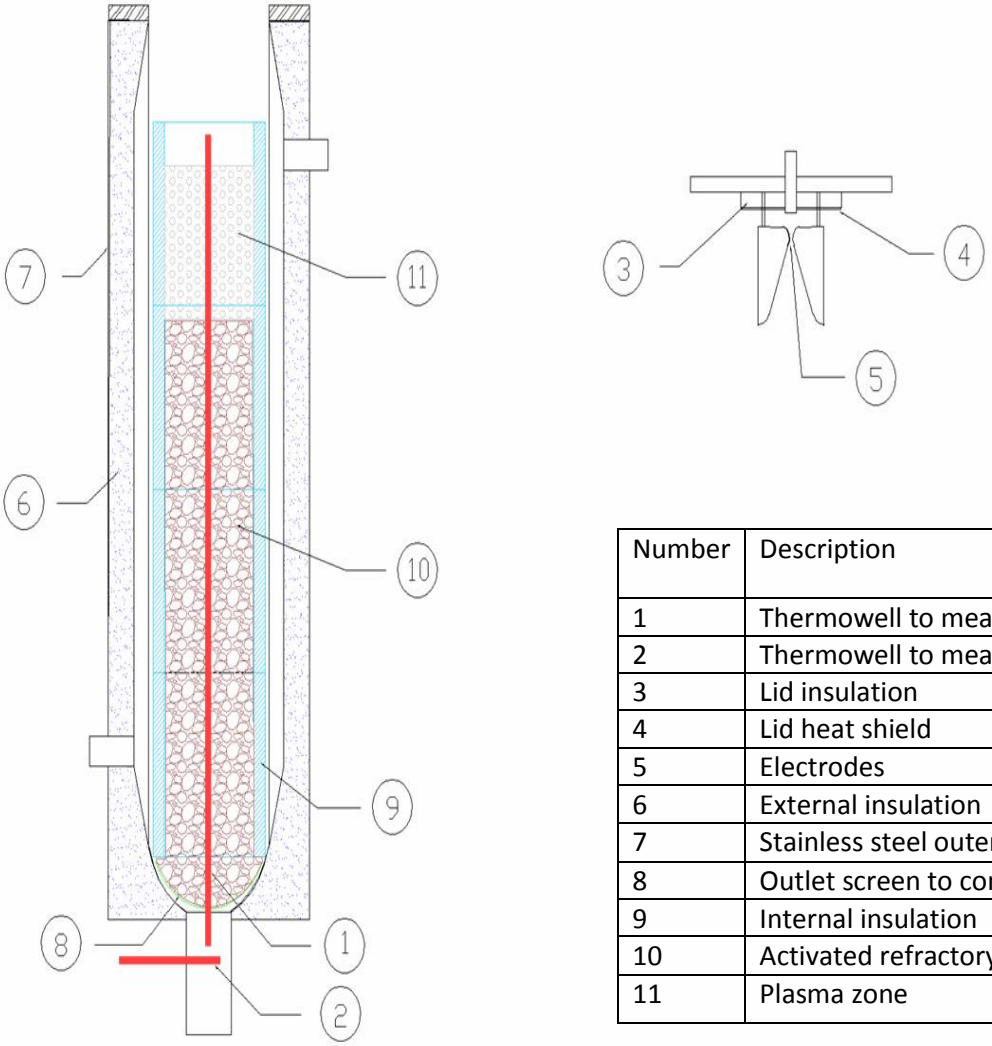
Water (as steam) and elemental nitrogen are exhausted up the stack instead of NOx, and potassium carbonate is once again present on the surface of the catalyst, allowing the oxidation/absorption cycle to begin again. There is not a net gain or net loss of potassium carbonate after the oxidation/absorption and regeneration cycle.

Regen System

To qualify for the "Green Power Switch", all energy sources utilized must be 100% renewable. To satisfy this requirement, a GlidArc plasma reformer fabricated by ECP of France was chosen. This unit had been demonstrated on many fuels including diesel, gasoline, natural gas, propane, canola, glycerol, and sugar water. The reformer was sized to mix approximately 3.5 gal/hr of biodiesel with 25 scfm of air and spray the mixture into an electric arc. The fuel penalty was 2.7%. When properly adjusted, the resulting regen gas is 18% H_2, 18% CO, N_2, H_2O, and CO_2. (For more information on GlidArc technology, see Attachment "C" and "D", specifically the sections referring to McMinnville Electric System)

Figure II-5

The GlidArc reformer (see **Figure II-5** and **Figure II-6**) is a cold plasma-assisted reformer that produces hydrogen and carbon monoxide through partial oxidation of liquid or gaseous fuels. A rich mixture of fuel, air, and water are sprayed through a low current, high-voltage gliding arc. The fuel is ignited by the arc and hot internals of the reformer. Excess fuel is converted to hydrogen and carbon monoxide in the in the activated refractory of the post-plasma zone. The entire reformer is surrounded by an annular pre-heat zone to pre-heat the air supply. The outside of the reformer is wrapped in ceramic wool insulation for safety.



Number	Description
1	Thermowell to measure internal temps
2	Thermowell to measure outlet temp
3	Lid insulation
4	Lid heat shield
5	Electrodes
6	External insulation
7	Stainless steel outer wrap
8	Outlet screen to contain refractory
9	Internal insulation
10	Activated refractory – post-plasma zone
11	Plasma zone

Figure II-6

For partial oxidation, the reforming temperature must be maintained between 800ºC and 1000ºC as shown in Figure II-7. This temperature is maintained through the addition of air and/or steam. Adding air alone increases the temperature of the reaction, and can lead to damaging the reformer internals. Adding steam alone decreases the temperature and can lead to soot formation. By adding the appropriate mixture of air and steam, a stable reformation temperature can be achieved, leading to the formation of maximum hydrogen.

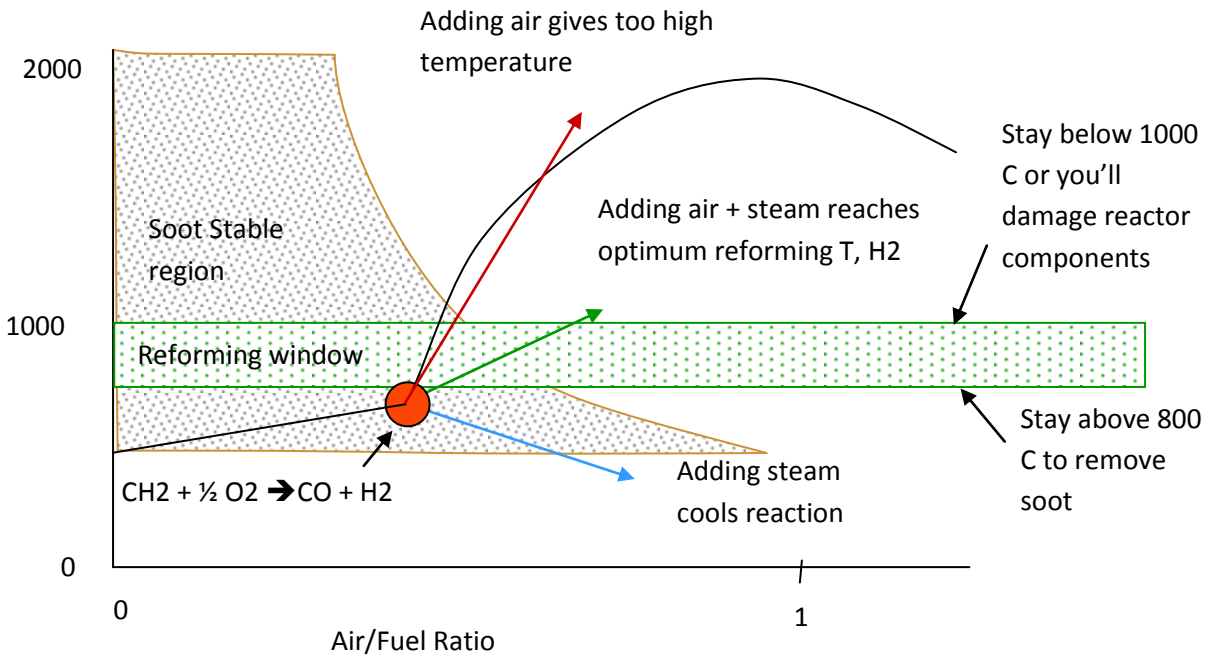


Figure II-7

Data Acquisition

The data acquisition system for the test included a gas chromatograph, a portable combustion analyzer, and a portable hydrogen analyzer as shown in **Figure II-8**. Exhaust was sampled from four positions:

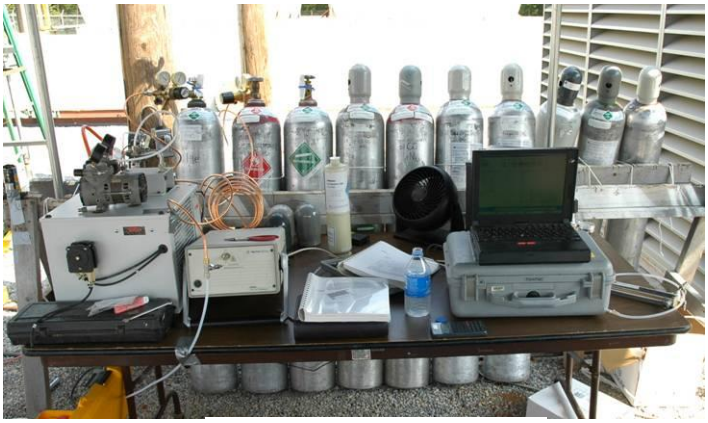


Figure II-8

1. "engine out" - upstream of the catalyst system
2. "catalyst out" – downstream of the catalyst system (inside the catalyst chamber, below the last module)
3. "system out) – downstream of the union joining the exhaust from both reactor chambers, as in **Figure II-9**
4. "regen inlet" – in the regen gas supply pipe

Dry gas from the chiller was analyzed with a gas chromatograph and a H_2 analyzer. The portable combustion analyzer was used to analyze the exhaust gas directly at the sample ports.

Temperature measurements were made upstream of the catalyst system. In addition, the catalyst temperature in each chamber was measured at one location downstream of the catalyst in each chamber. A manometer was used to sample the exhaust pressure upstream and downstream of the catalyst system.

Figure II-9

Original Test Plan

The installation and commissioning of the components and the system was planned for 6/28/05 through 7/3/05. During this time, the following steps were planned:

1. Install plasma reformer and connect engine exhaust to the EMx emission control system

2. Start the plasma reformer and optimize operation
3. Run the plasma reformer for 24 hour to verify long-term stability
4. Install the EMx catalyst
5. Start the engine and optimize the function of complete system
6. Verify oxygen depletion in the chamber during regen, as an indication that regen gas was reaching all of the modules
7. Verify sufficient mass flow rate of hydrogen content in the regen gas for complete regeneration of the modules

After commissioning the system, we would begin a series of short term tests. Each test would last 4 hours, with sampling beginning 2 hours into the test. After each test, the catalyst would be washed to re-establish the baseline. The fuels tested would be ULSD, 2% biodiesel, 5% biodiesel, 20% biodiesel, 50% biodiesel, and 100% biodiesel.

Long-term test would follow, using only 100% biodiesel. The test would last 1500 hours, with stops at 500, 1000, and 1500 hours for Caterpillar to inspect the engine for wear and inspect the fuel filters and injectors for blockage.

Installation and Commissioning

Table III-1 summarizes the plasma reformer runs during installation and commissioning. The engine was not operating and the EMx catalyst was not installed until just before run 9. Start-up issues such as overheating, soot built-up and insufficient supplies of ULSD prevented a 24 hour run of the plasma reformer prior to EMx system start-up.

Run	Date	Fuel	Duration	Reason Stopped	Comments
1	6/29/05	ULSD	0:24	End of day	
2	6/30/05	ULSD	1:29	Flare impinging on isolation valve actuator	
3	6/30/05	ULSD	1:33	End of day	13% H2, no soot, full air and fuel flow for 30 minutes
4	7/1/05	ULSD	1:09	Storm/lightening	18% H2, no soot, invisible flame H2 flow – 0.924 kg/hr, Total regen gas flow – 35.1 scfm
5	7/1/05	ULSD	0:25	Reformer thermowell breached	Fuel valve closed, mixture went lean, max temp ~ 1271 ˚C
6	7/2/05	ULSD	1:51	End of day	New thermowell, H2 – 15.2% - 18.5%, CO ~ 18%
7	7/3/05	B100	0:55	Storm/lightening	

8	7/3/05	B100	2:25	Test complete	Changed to larger fuel and water lines, H2 – 21% - 23.5%, CO ~ 21%
9	7/3/05	USLFO	1:00	End of day	Initial loading of catalyst. Closed vent - Cycling regen gas through EMx (engine off)
10	7/4/05	ULSD	4:33	Decreasing air flow	Electrodes, Ni balls & thermowell in good condition
11	7/5/05	ULSD	7:17	Decreasing air flow, concerned about soot formation	Post-run inspection revealed heavy carbon buildup, some fusing of catalyst media, some Ni balls fused

Table III-1

Figure III-1 shows the increase in the chamber temperature (with catalyst installed) during startup as well as the untreated engine CO and NOx emissions during start-up. Both the temperature and emissions are stabilized in less than 1 hour.

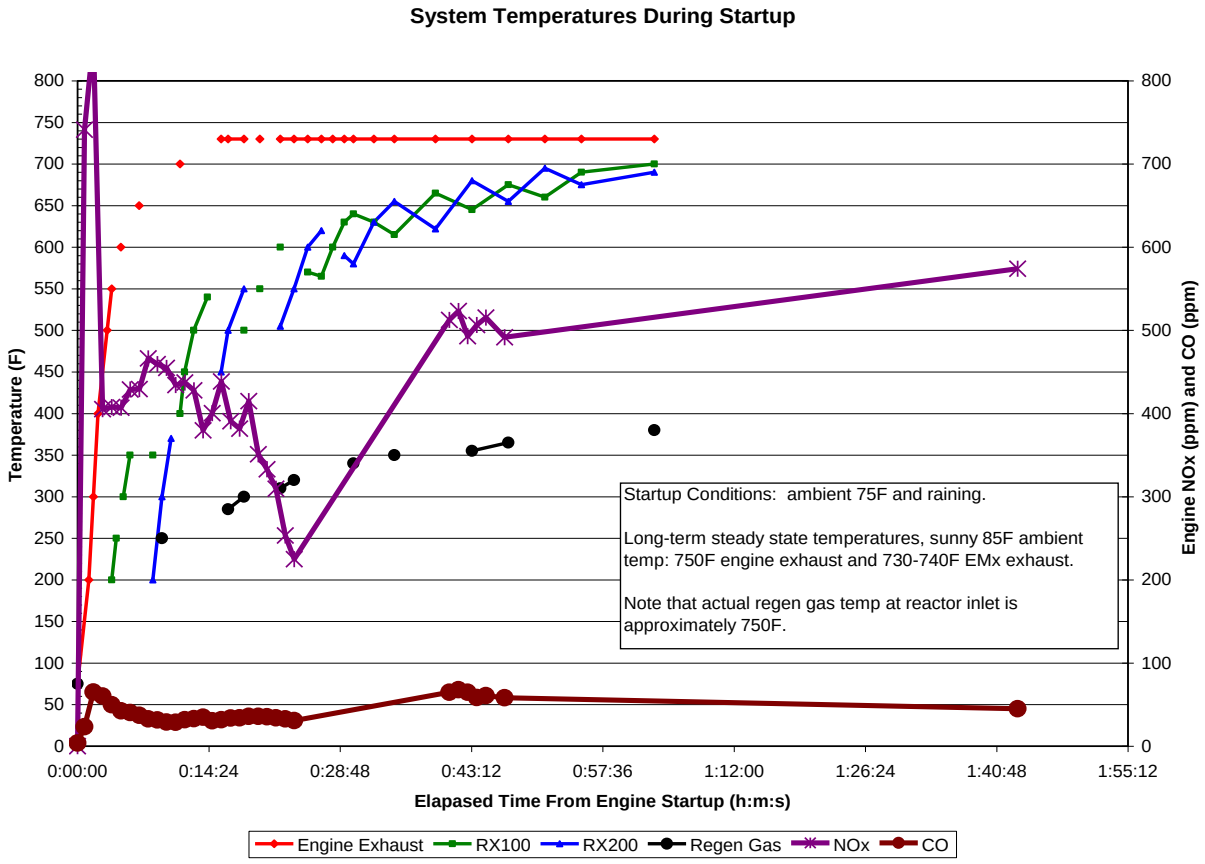


Figure III-1

Figure III-2 shows the oxygen depletion in both chambers measured approximately 1 foot below (downstream) of the last catalyst module. Chamber RX100 is slower to respond and is not reaching as low of a level of oxygen concentration as chamber RX200. This could indicate a small leak in the isolation valve (allowing engine exhaust to leak into the chamber during regen) or a leak in the regen gas supply line (lowering the flow rate of regen gas into the chamber).

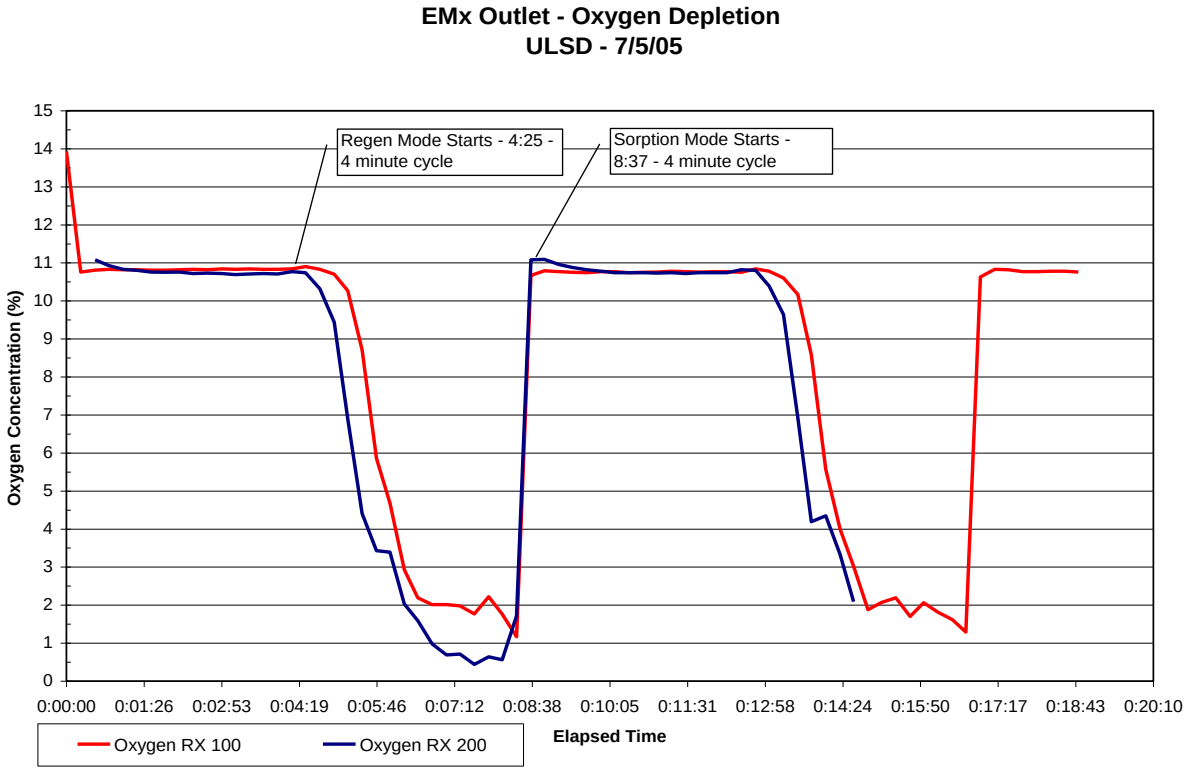


Figure III-2

Figure III-3 shows the NOx concentration in each chamber below the last EMx module throughout the cycle on one of the commissioning runs using ULSD. These measurements were not simultaneous, but were overlaid to represent the same point in the sorption/regen cycle. These values indicate the concentration in ppm of NOx in the reactor chamber downstream of the catalyst and have not been normalized for flow rates. (During regen, the concentration of NOx was high, but the flow rate was very low – approximately 0.7% of engine flow, so the effect that it had at the stack was very low.) Chamber RX200 is capturing more NOx than Chamber RX 100. This could be caused by lower NOx sorption capacity due to insufficient regeneration or by untreated exhaust leakage past the catalyst modules in this chamber.

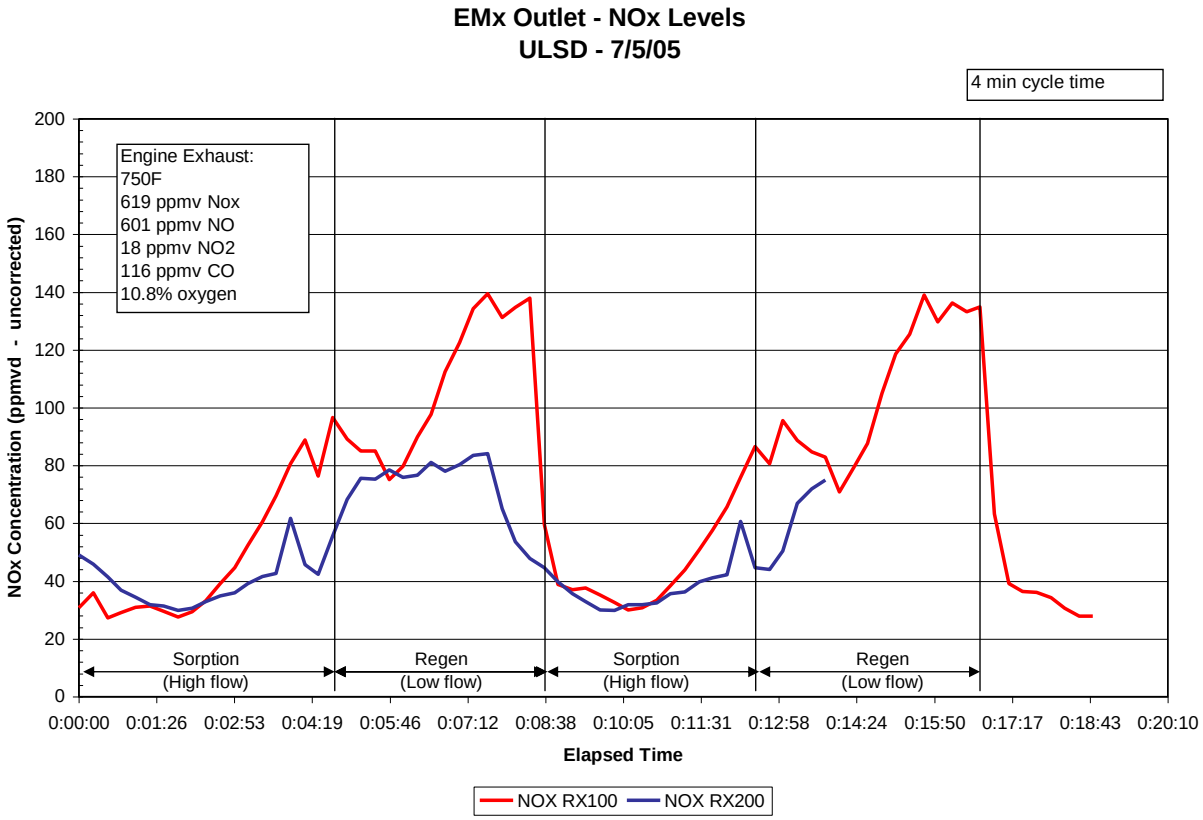


Figure III-3

Figure III-4 shows the CO concentration in each chamber below (downstream of) the last EMx module throughout the cycle. These measurements were not simultaneous, but were overlaid to represent the same point in the sorption/regen cycle. These values indicate the concentration in ppm of CO in the reactor chamber downstream of the catalyst and have not been normalized for flow rates. (During regen, the concentration of CO was high, but the flow rate was very low – approximately 0.7% of engine flow, so the effect that it had at the stack was very low.) The slow drop in CO concentration during later sorption cycles represents the slow recovery of the analyzer after exposure to very high concentrations of CO, and does not represent actual CO outlet concentrations during sorption. The first sorption cycle is indicative of actual CO outlet concentrations.

Chamber RX100 is releasing much less CO than chamber RX200 during regeneration. This seems to indicate the chamber RX100 is not getting sufficient regeneration, therefore more of the CO is getting used as the reducing agent to regenerate the catalyst.

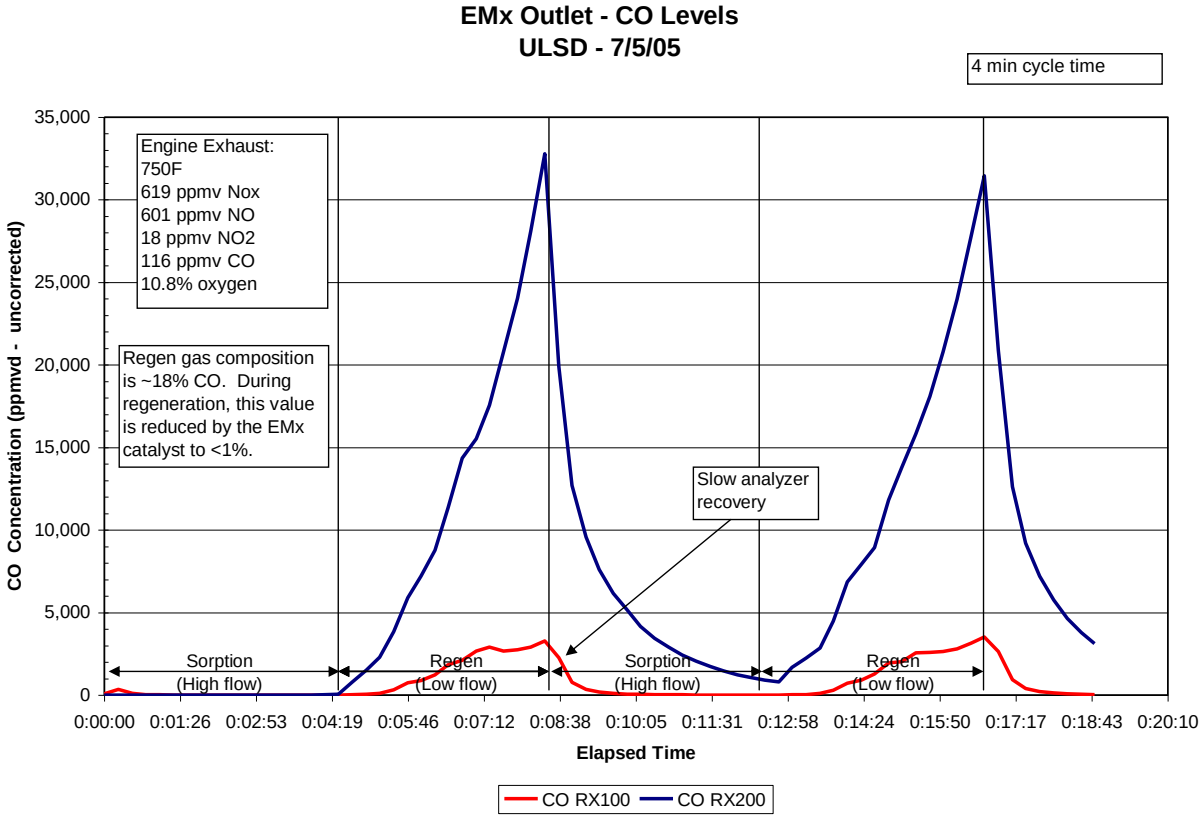


Figure III-4

Figure III-5 shows the results of the NOx capacity test run on chamber RX100. Earlier, observations were made that indicate that chamber RX100 is not achieving full regeneration:

1. Figure III-2 shows that the concentration of oxygen in chamber RX100 is getting reduced slower than in chamber RX200
2. Figure III-2 also shows that the minimum concentration of oxygen achieved in chamber RX100 is 1-2%, which is higher than chamber RX200.
3. Figure III-3 shows that chamber RX100 has a higher NOx outlet concentration during sorption than chamber RX200.
4. Figure III-4 shows that chamber RX100 has a lower CO outlet concentration during regeneration than chamber RX200.
5. We later learned that a significant amount of untreated engine exhaust was leaking around the catalyst and influencing the outlet NOx values.

All of these observations indicate that the catalyst in chamber RX100 is not performing as well as it could be. The regen gas is displacing the exhaust gas at a slower rate and does not appear to be fully displacing the exhaust gas during the regen cycle. This chamber is relying on the CO in the regen gas to regenerate the catalyst. The catalyst in chamber RX100 is not performing as well as the catalyst in RX200. The actual sorption capacity of EMx catalyst under these conditions is therefore higher than this graph would indicate. This data SHOULD NOT be used as a representation of the maximum capacity of EMx catalyst at this temperature and space velocity.

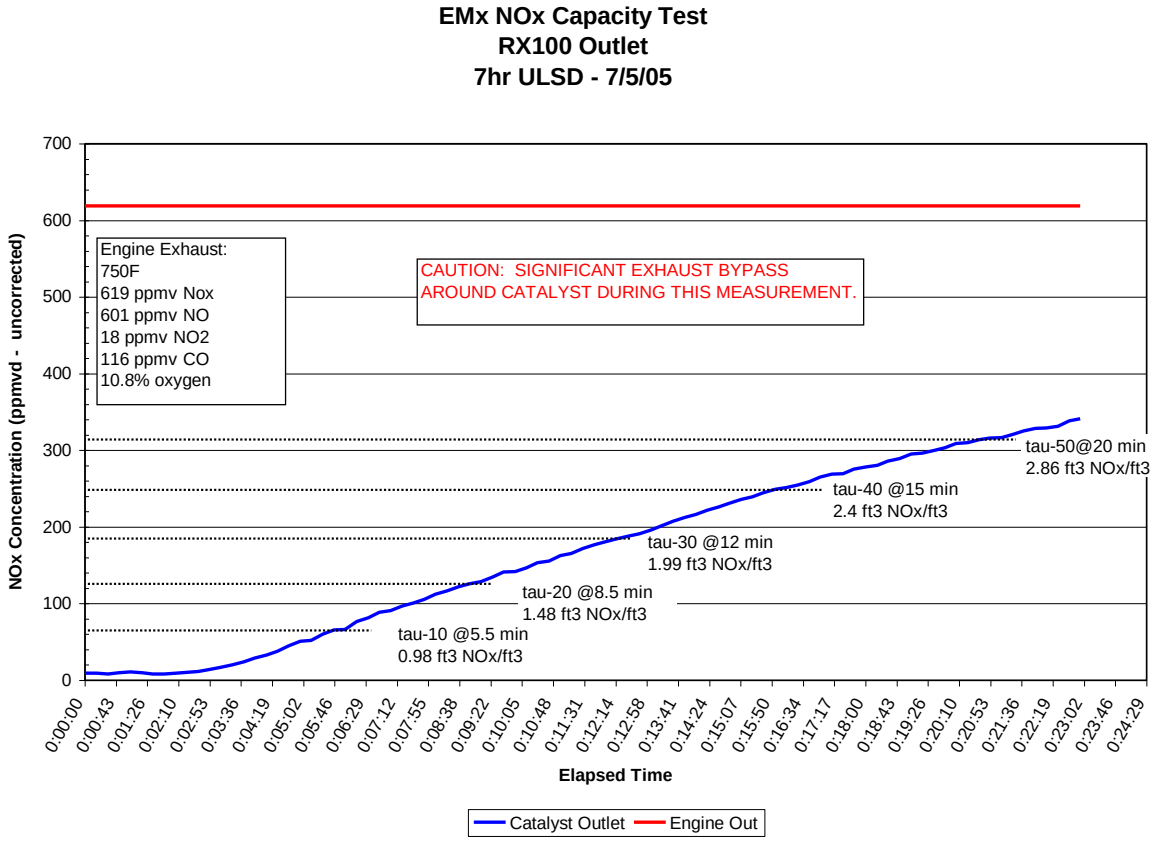


Figure III-5

Figure III-6 shows the long term CO emissions during the NOx capacity test. The CO outlet slightly increases over the duration of the test. This confirms that the oxidation performance of the catalyst is virtually unaffected by the level of saturation of the NOx sorbent.

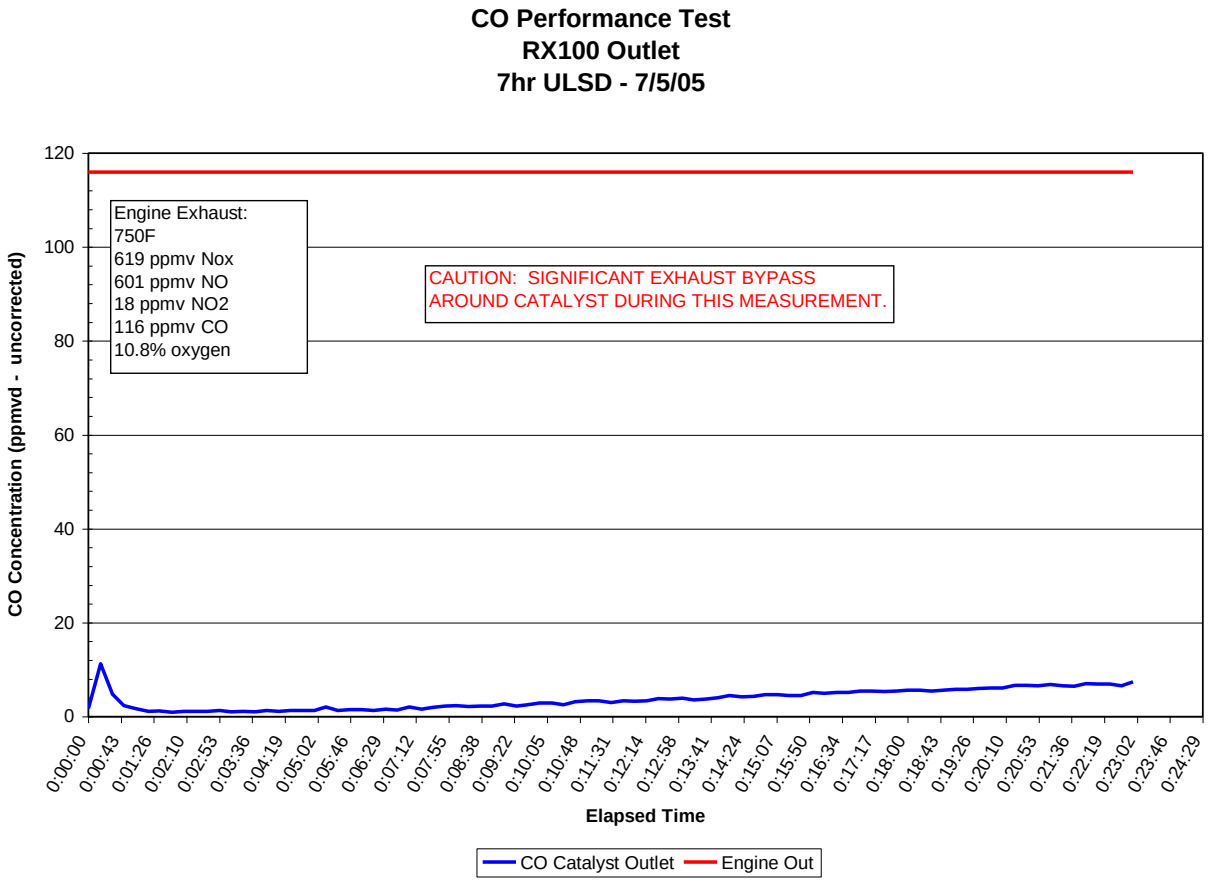


Figure III-6

Short Term Fuel Blend Testing

ULSD Test

Figure IV-1 shows the engine emissions of NOx and CO when the engine is running ultra-low sulfur diesel as fuel. **Figure IV-2** shows the catalyst outlet emissions measured in the common exhaust stack for both reactor chambers. The measurements combine the treated engine exhaust from the chamber in absorption mode with the spent regen gas leaving the chamber in regeneration mode. The NOx removal for both chambers averages 80%. We later learned that a significant amount of untreated engine exhaust was leaking around the catalyst and influencing the outlet NOx values. The NOx emissions for RX 100 are higher than those for RX 200 as observed during installation and commissioning. The CO spikes are due to the high CO concentration regeneration gas being swept in a plug flow from the chamber that was in regeneration. The higher CO spike is from regeneration on chamber RX 200, as observed during installation and commissioning.

Figure IV-3 shows the CO removal if we remove the effects of the CO in the regen gas. This would indicate that a CO removal efficiency of 95.5% would have been measured if a shift reactor were added to remove the CO from the regen gas. This CO removal efficiency is low for an oxidation catalyst with this level of precious metal loading when operated at 750˚F at this gas hourly space velocity. This low oxidation performance indicates exhaust gas bypass around the catalyst.

The pressure drop from the engine exhaust pipe ahead of the reactor to just below the catalyst (during sorption) was measured to be 16.2" H_2O. This includes pressure drop through the elbows, the open isolation valve, the perforated diffuser plate, the catalyst, the 180˚ turn in the reactor, and the union joining the two reactor exhaust stacks.

For this test, the plasma reformer was run for a total of 10 hours, 20 minutes. The air flow remained steady for the run, ranging from 20.7 scfm at 13:20 to 19.8 at 19:50. The regen gas was composed of 19.6% hydrogen, 18.7% carbon monoxide, 54.5% nitrogen, 1.6% methane, and unmeasured concentrations of carbon dioxide and water vapor.

After the ULSD fuel blend test, the catalyst was chemically washed to remove any sulfur and any other masking agents that may have accumulated on the catalyst. The modules were still slightly damp when they were re-installed into the chamber.

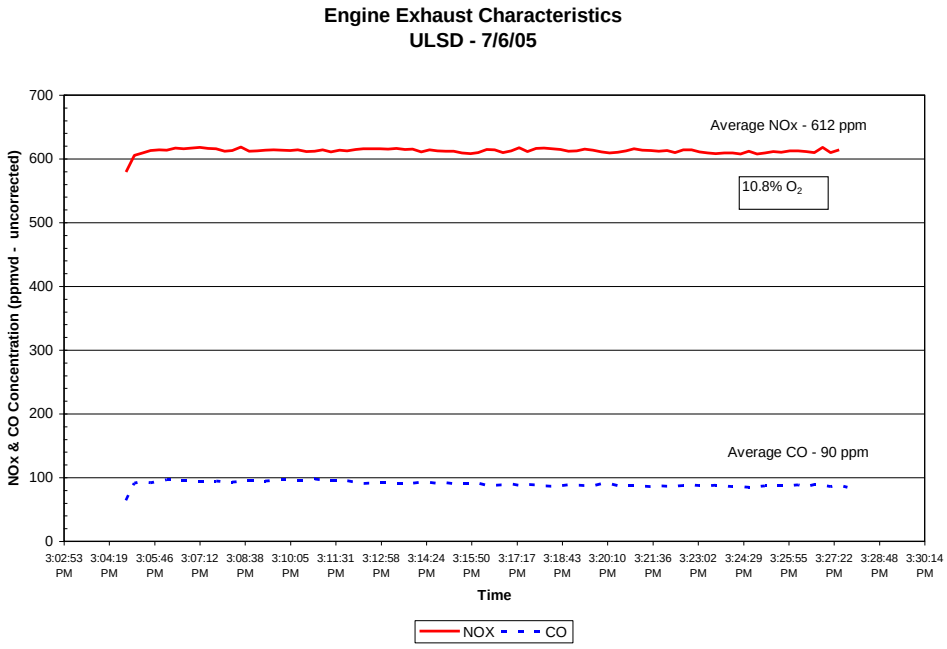


Figure IV-1

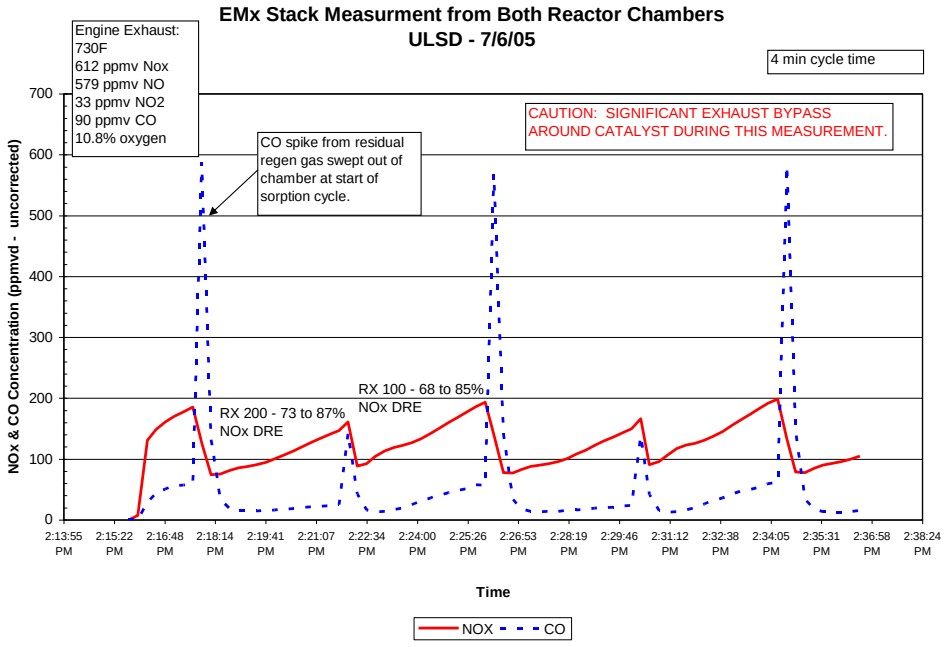


Figure IV-2

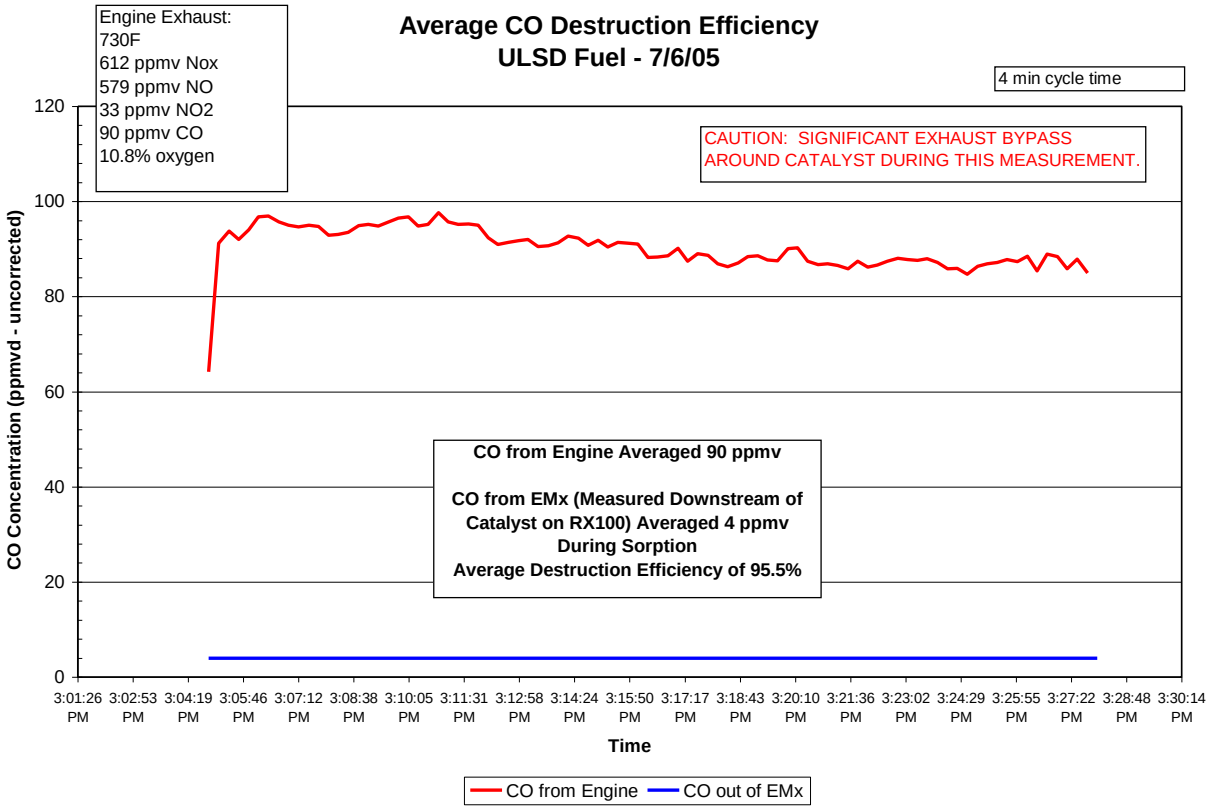


Figure IV-3

B2 Test

Figure IV-4 shows the engine emissions of NOx and CO when the engine is running 98% ultra-low sulfur diesel mixed with 2% biodiesel as fuel. **Figure IV-5** shows the catalyst outlet emissions. The NOx removal for both chambers averages 88%. The NOx emissions for both chambers are lower than in the previous test, but the discrepancy between the two is greater. The CO spikes are much lower than in the previous test. It was later discovered that exhaust bypass around the catalyst was occurring.

The pressure drop from the engine exhaust pipe ahead of the reactor to just below the catalyst (during sorption) was measured to be 15.1" H_2O on the RX100 chamber and 16.7" H_2O on the RX200 chamber side.

For this test, the plasma reformer was run for a total of 8 hours, 5 minutes. The regen gas was composed of 17.2% hydrogen, 17.1% carbon monoxide, 54.9% nitrogen, and 1.6% methane, and unmeasured concentrations of carbon dioxide and water vapor. The regen gas flow rate was calculated to be 31.5 scfm (76 acfm) versus design specification of 35 scfm. The hydrogen flow rate was calculated to be 0.76 kg/hr versus design specification of 1 kg/hr. The plasma

reformer's flow rate and hydrogen concentration were below the design specification, which adversely affected the EMx catalyst performance.

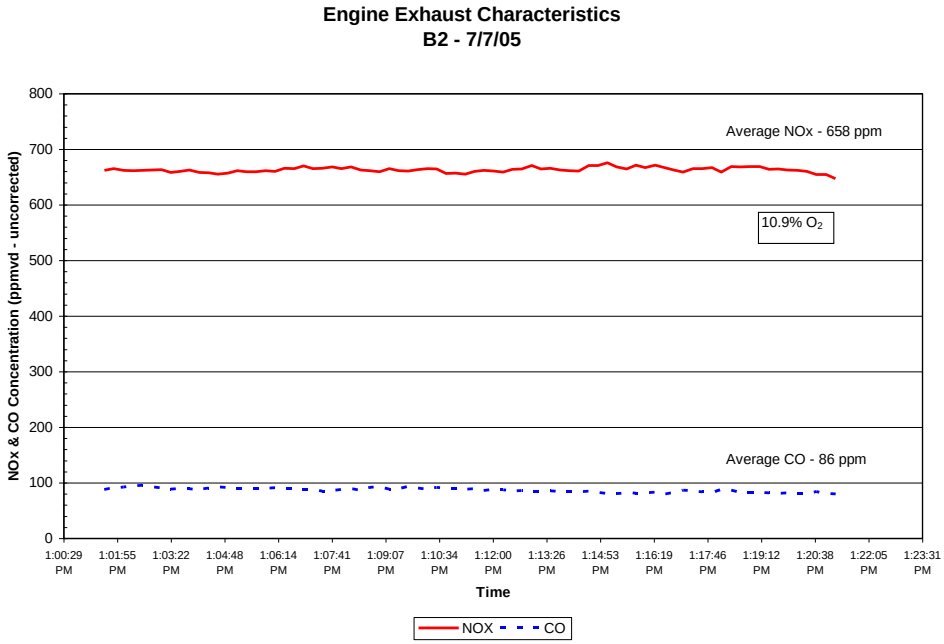


Figure IV-4

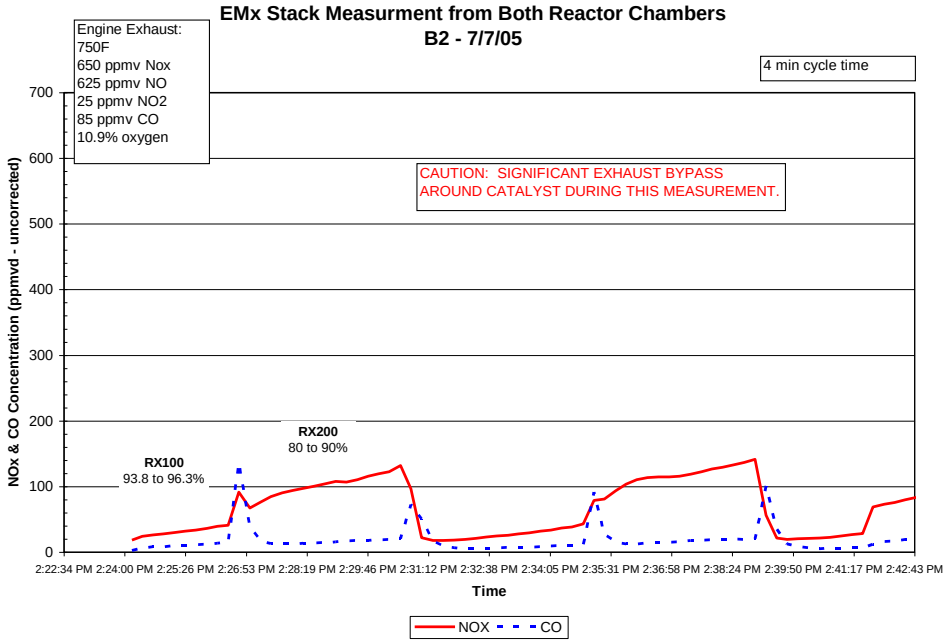


Figure IV-5

B5 Test

Figure IV-6 shows the engine emissions of NOx and CO when the engine is running 95% ultra-low sulfur diesel mixed with 5% biodiesel as fuel. **Figure IV-7** shows the catalyst outlet emissions. The NOx removal for both chambers averages 72%. The discrepancy in NOx emissions for the two chambers continues to grow. The CO spikes are higher than the previous test, but lower than the ULSD test. It was later discovered that exhaust bypass around the catalyst was occurring.

For this test, the plasma reformer was changed from B2 to B5 while running and continued to run for another 2 hours, 13 minutes. The regen gas was composed of 17.2% hydrogen, 17.0% carbon monoxide, 52.6% nitrogen, and 1.5% methane, and unmeasured concentrations of carbon dioxide and water vapor.

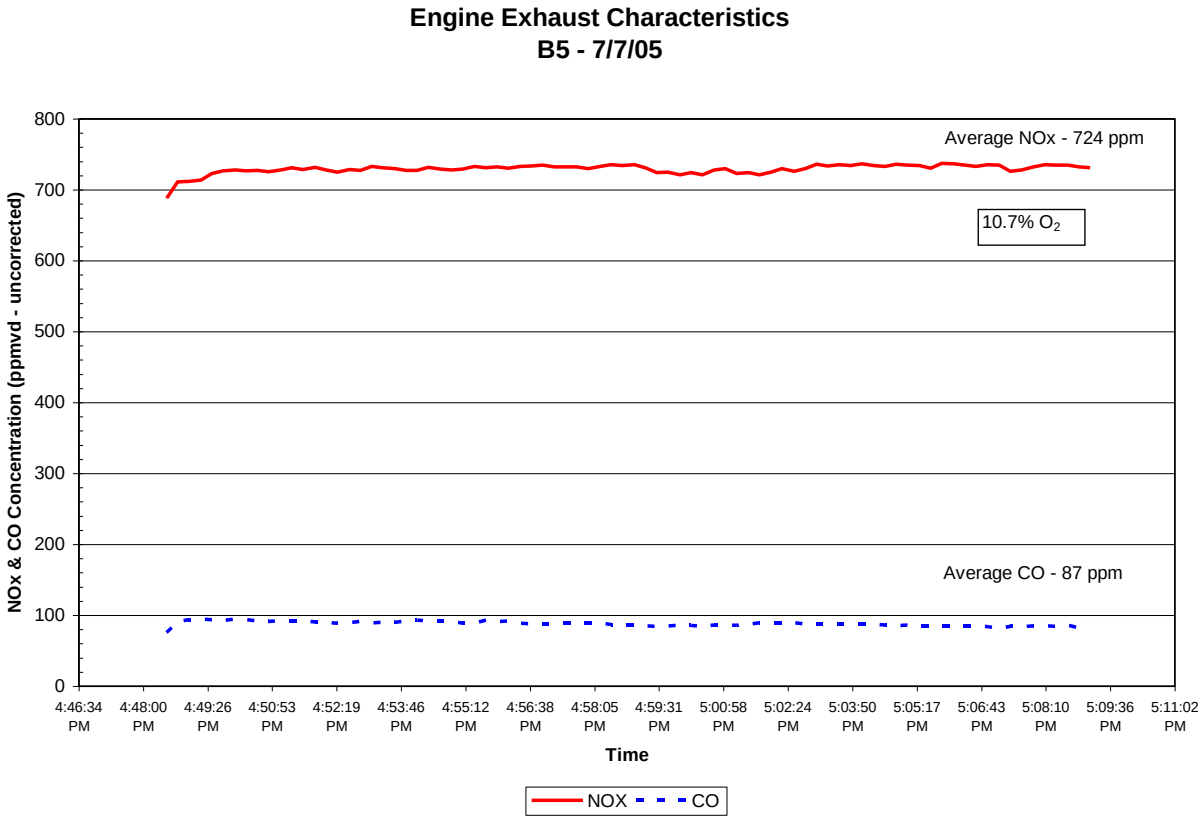


Figure IV-6

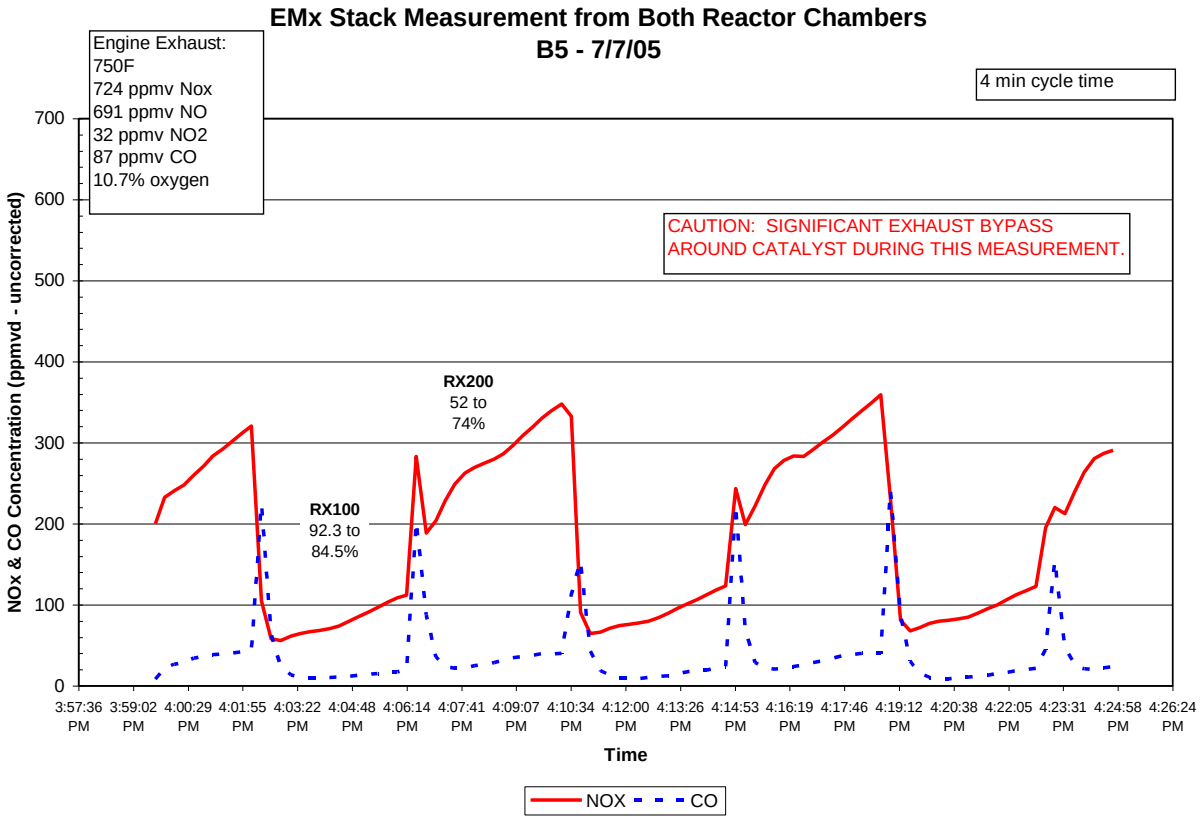


Figure IV-7

Observations on ULSD, B2 and B5 Short Term Fuel Blend Tests

The incoming NOx levels were much higher than were expected. At an inlet concentration of nearly 700ppm, the flow rate of NOx is approximately 4.2 scfm or 16.8 ft3 in a 4 minute cycle. This consumes 84% of the measured Tau 10 capacity. This minimizes the safety factor to compensate leakage or inefficient regeneration. Reducing the cycle time to 3 minutes would reduce the loading to 63% of the Tau 10 capacity.

More hydrogen is needed for regeneration to compensate for the higher incoming NOx loading. The primary reaction taking place is:

$$KNO_3 + 3H_2 = 3H_2O + \tfrac{1}{2}\ N_2$$

$$\frac{16.8\ ft^3 NOx}{4\ \text{min}} * \frac{1 moleNO_2}{379\ ft^3} * \frac{3 molesH_2}{moleNO_2} * \frac{2 lbH_2}{moleH_2} = .266\ lbH_2/cycle$$

$$\frac{0.266\ \text{lb}\ H_2}{\text{cycle}} * \frac{15\ \text{cycles}}{\text{hour}} = 4\ \text{lb}\ H_2/\text{hour} = 1.8\ \text{Kg}\ H_2/\text{hour}$$

As noted during the B2 fuel blend test, the actual hydrogen production was measured at 0.76 kg/hr. This is 42% of the minimum theoretical requirement.

Fortunately, CO is contributing to regen. Regen gas containing approximately 18% CO is reduced to approximately 2% after catalyst during regen. This suggests that the CO is a strong reductant, contributing to the regeneration of the catalyst.

It should be noted that the actual time available for regeneration was less than 4 minutes. During the oxygen depletion study, it was shown that it took approximately 1 ½ minutes for the oxygen to be depleted. Depending on the mixing in the chamber, some of the hydrogen is reacting with the oxygen present. As the chamber fills with regen gas, it begins to move in a plug flow through the catalyst modules and displaces the oxygen. Regeneration will not begin until regen gas containing hydrogen and carbon monoxide reaches the first row of catalyst, most likely after plug flow is established. At the end of the cycle, regen gas that is introduced in approximately the last 30 seconds does not reach the last row of catalyst before the sorption cycle begins and the regen gas is swept out of the chamber by the engine exhaust.

The performance of chamber RX 200 has degraded significantly throughout the course of the tests. The performance of chamber RX 100 has fluctuated, but remained close to 90% at its peak value. It appears that chamber RX 200 is not getting sufficient regeneration, and the working capacity is steadily decreasing as a result. Bypass could also be worsening as the wall separating the two chambers warps.

Furthermore, leaks have been witnessed around the doors of the chambers, which is not only dangerous for the on-site observers, but can reduce the affectivity of the regeneration. When the catalyst chamber was opened for inspection and to wash the catalyst, black leak paths were observed at the corners of the catalyst as shown in **Figure IV-8** indicating that exhaust and regen gas were leaking out of the doors and around the catalyst modules. A leak path was also identified behind the catalyst. The chambers had a common wall on the back that was a flat plate of carbon steel. During the initial heat-up of the system, the wall was subjected to uneven heating as first one side of the wall was heated and then the other. As a result, the wall warped, leaving a leak path behind the modules as shown in **Figure IV-9**.

When the catalyst modules were chemically washed after the B2 and B5 fuel blend runs, the wash solution was unusually dirty. There was a high amount of floating, black, oily matter that would rise out of the blocks. The surface of the dry blocks, even the 4th downstream row, had oil that could be wiped off with a finger. After 5 modules had been washed, tank 1 looked like dense brown, turbid muddy water. Sludge had already begun to accumulate on the bottom of the tank. Tank 1 needed original charge plus 2 additional changes to wash 16 modules. We concluded that some of the washes were not effective, and may have re-contaminated the catalyst with oil.

Figure IV-8

Figure IV-9

Before the start of the B20 testing, some modifications were made to improve the results. The sorption/regen cycle time was reduced to 3.5 minutes. Gaskets were added to the door to improve sealing on the front side of the catalyst as seen in **Figure IV-10**. Bars were added to the back wall of the catalyst chamber to straighten the wall and to act as a labyrinth seal as seen in **Figure IV-11**. On the plasma reformer, the catalyst media was re-activated using Ni salts, a short section of small diameter pipe at the reformer inlet was removed to increase the regen gas flow and hydrogen flow rate, and a small supply of water was added downstream of the reformer to add steam to the regen gas and increase the regen gas flow rate.

Figure IV-10

Figure IV-11

B20 Test

Figure IV-12 shows the engine emissions of NOx and CO when the engine is running 80% ultra-low sulfur diesel mixed with 20% biodiesel as fuel. Compared to **Figure IV-6**, note that NOx emissions decreased from an average of 724 ppm to an average of 619 ppm. **Figure IV-13** and **Figure IV-14** show the catalyst outlet emissions. The NOx removal for both chambers averages 97%. The revisions made to the system seem to have removed the discrepancy in NOx removal between the two chambers observed during installation and commissioning and earlier testing. The CO spike from regeneration is still higher for one chamber than the other, as observed during earlier testing, indicating that there is still a discrepancy in regen efficiency between the two chambers. The CO spike is significantly higher for this test than in previous testing. This may indicate that the catalyst is fully regenerated by the hydrogen in the regen gas and therefore consuming less CO or that there is less oxygen present in the chamber, which would allow the CO to oxidize to CO_2.

Figure IV-15 shows the oxygen depletion study as repeated on chamber RX100. The increased flow rate of regen gas has decreased the amount of time required for the chamber to be purged. In supplementary testing, the oxygen concentration in chamber RX100 was down to 0.5% in 1:50 minutes, and down to 0.0% in 2:20 minutes. For chamber RX200, the oxygen concentration was down to 0.5% in 3:02 minutes and down to 0.0% in 3:40 minutes. The minimum oxygen concentration achieved was 0%, which was not achieved in the earlier oxygen depletion testing. The oxygen concentration in chamber RX100 was below 2% by 54 seconds into the regeneration cycle.

For this test, the plasma reformer was run for a total of 7 hours, 38 minutes total, with a switch to B50 about 5 hours into the test. Approximately 23 liters per hour of water was added as a secondary supply of steam to the regen gas. This rate of water injection far exceeded the amount of heat available to vaporize it (even if it had been finely atomized). As a result, water accumulated in the bottom of the regen outlet piping, increased the resistance of the system and eventually reduced the air flow rate. Small droplets of grey/black water were showering from the vent stack. During the B20 portion of the test, the regen gas was composed of 19.2% hydrogen, 19.8% carbon monoxide, 52% nitrogen, and 0.86% methane, and unmeasured concentrations of carbon dioxide and water vapor.

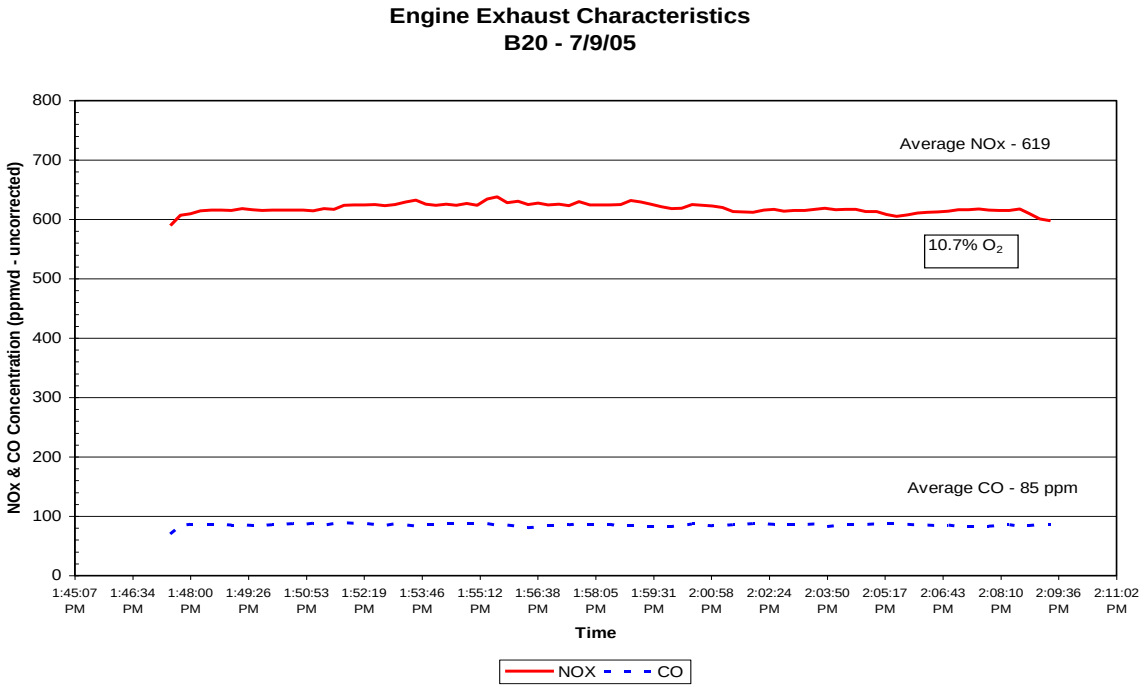


Figure IV-12

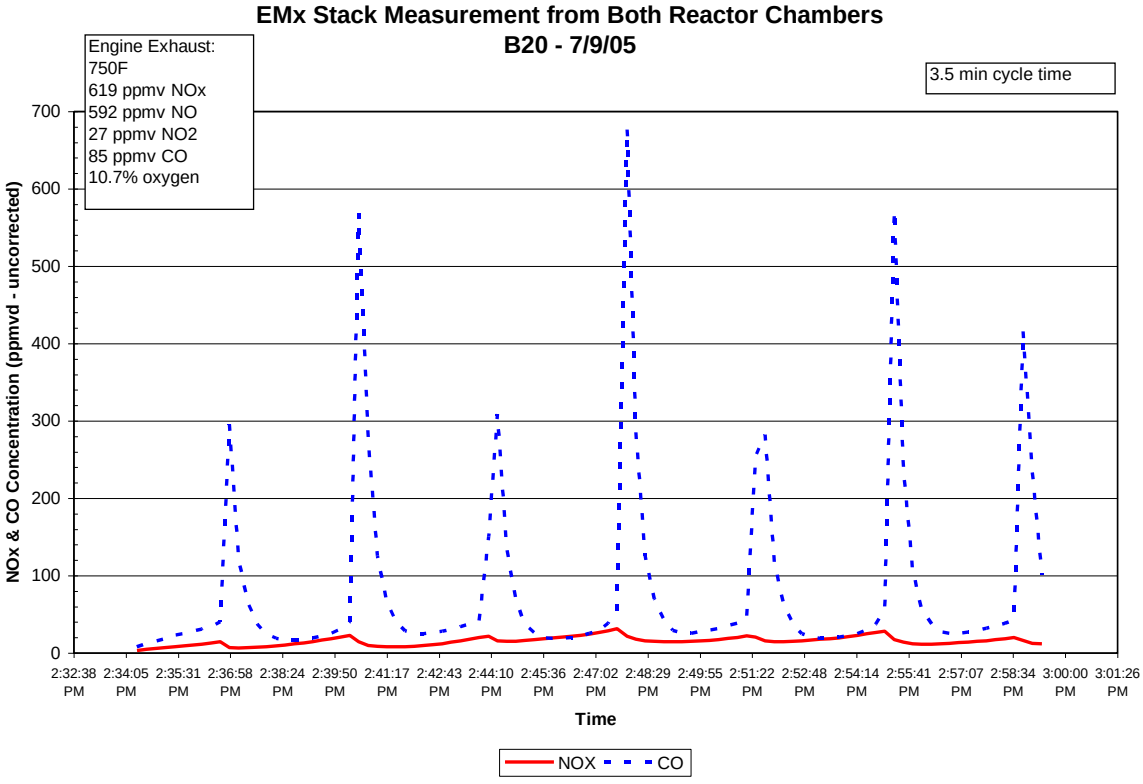


Figure IV-13

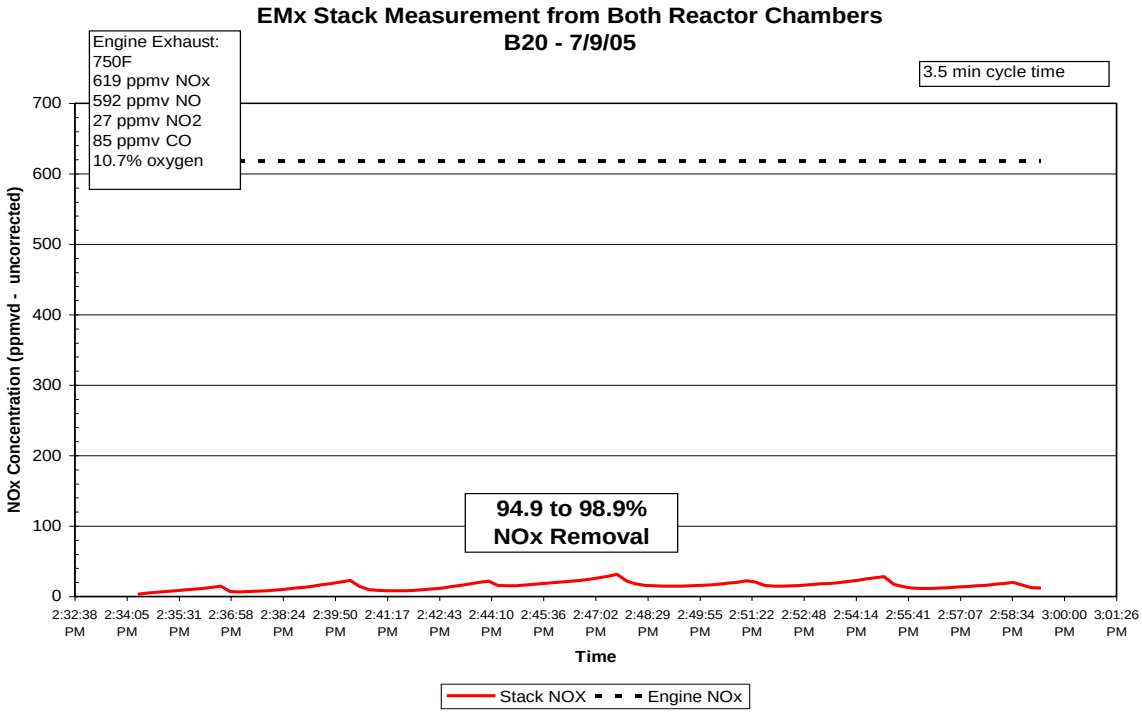


Figure IV-14

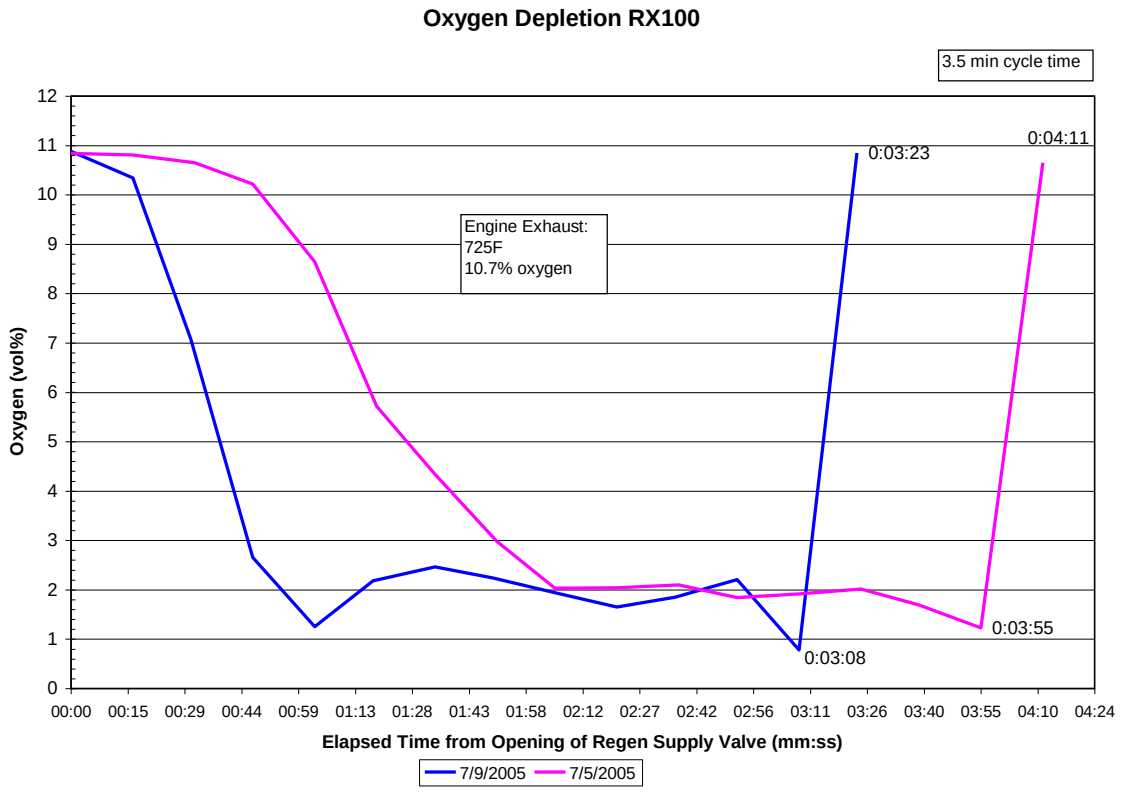


Figure IV-15

B50 Test

Figure IV-16 shows the engine emissions of NOx and CO when the engine is running 50% ultra-low sulfur diesel mixed with 50% biodiesel as fuel. **Figure IV-17** and **Figure IV-18** show the catalyst outlet emissions. The NOx removal for both chambers averages 98%. The NOx removal is nearly identical between the two.

The pressure drop from the engine exhaust pipe ahead of the reactor to just below the catalyst (during sorption) was measured to be 13.5" H_2O on the RX100 chamber and 14.9" H_2O on the RX200 chamber side.

For this test, the plasma reformer was run for a total of 7 hours, 38 minutes total, with a switch to B50 about 5 hours into the test. During the B50 portion of the test, the regen gas was composed of 19.3% hydrogen, 18.2% carbon monoxide, 50.8% nitrogen, and 1.5% methane, and unmeasured concentrations of carbon dioxide and water vapor. The regen gas flow rate was calculated to be 39.9 scfm (91.3 acfm). The hydrogen flow rate was calculated to be 1.24 kg/hr. This flow rate and hydrogen production rate exceed the design specification.

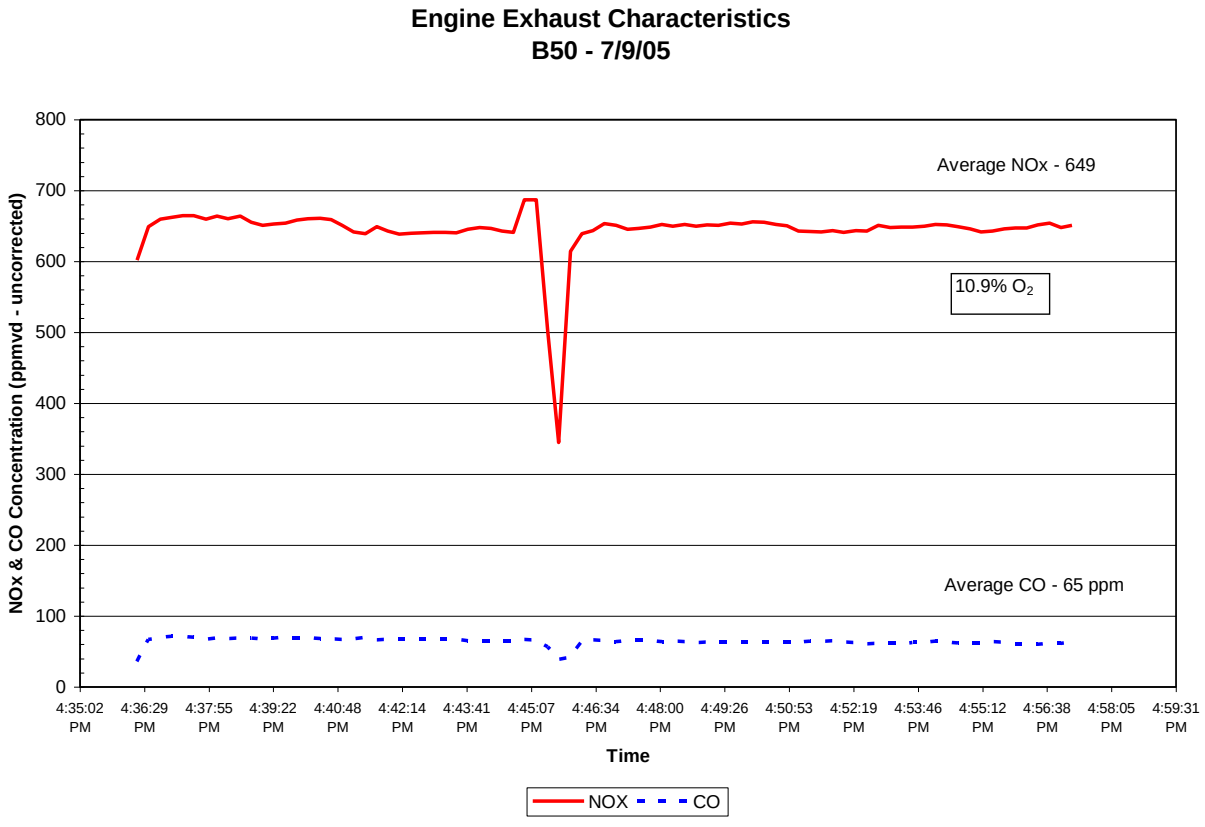


Figure IV-16

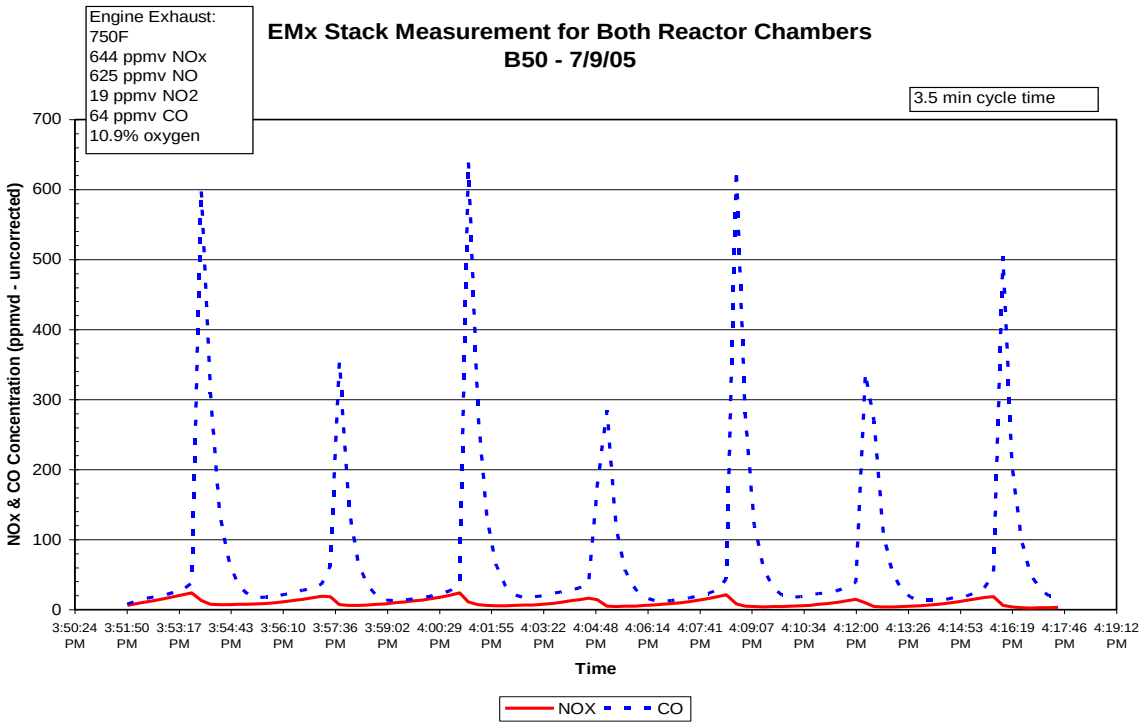


Figure IV-17

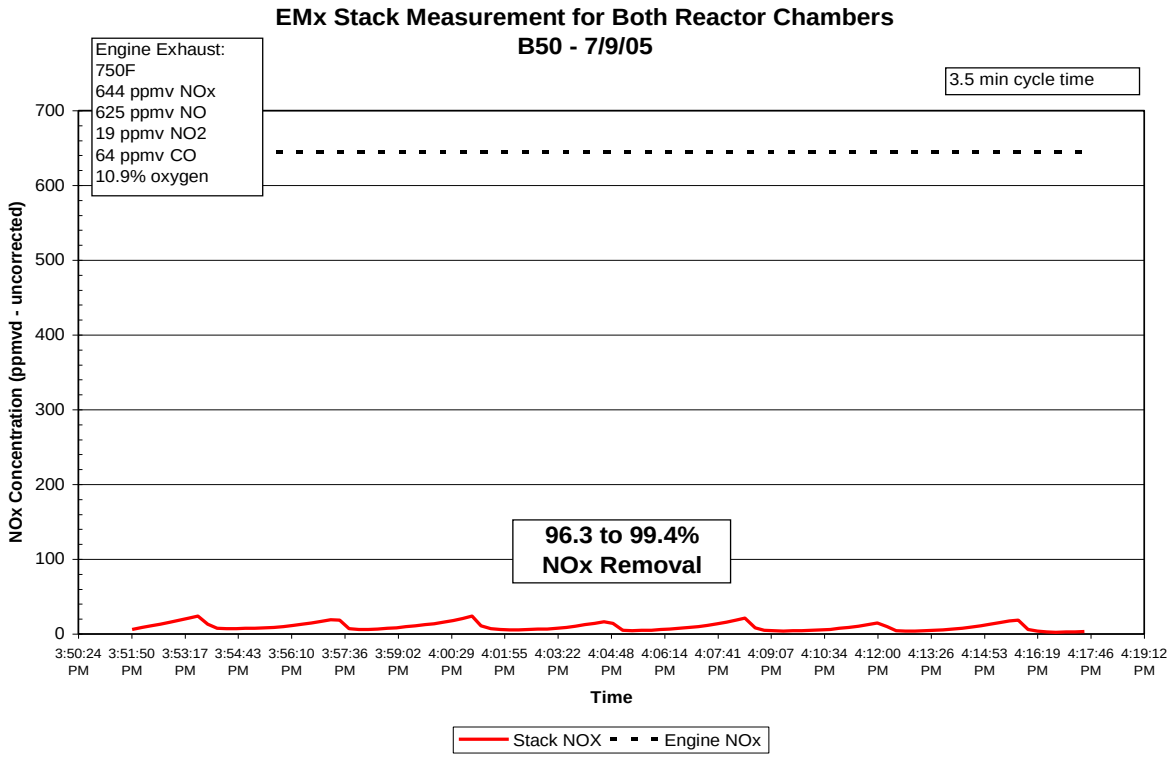


Figure IV-18

B100 Test

Figure IV-19 shows the engine emissions of NOx and CO when the engine is running 100% biodiesel as fuel. The NOx concentration of 786 ppm is an 18% increase over the B50 NOx emissions of 649 ppm and a 25% increase over the ULSD emissions of 612 ppm. **Figure IV-20** and **Figure IV-21** show the catalyst outlet emissions. The NOx removal for both chambers averages 96.6%. The NOx emissions for one chamber are slightly higher than those for the other chamber. The CO spikes slightly higher than the previous test, and displays a less consistent pattern.

For this test, the plasma reformer was run for a total of 5 hours, 4 minutes. The regen gas was composed of 19% hydrogen, 18.4% carbon monoxide, 54% nitrogen, and 0.83% methane, and unmeasured concentrations of carbon dioxide and water vapor. The hydrogen concentration remained steady throughout the test, varying from 17.5% to 20%.

TVA had defined a target NOx emission level of 0.5 g/bhp-hr for the system, when running on B100. For this test, we calculated a NOx emission level of 0l21 g/BHP-hr, far exceeding the required reduction in NOx emissions.

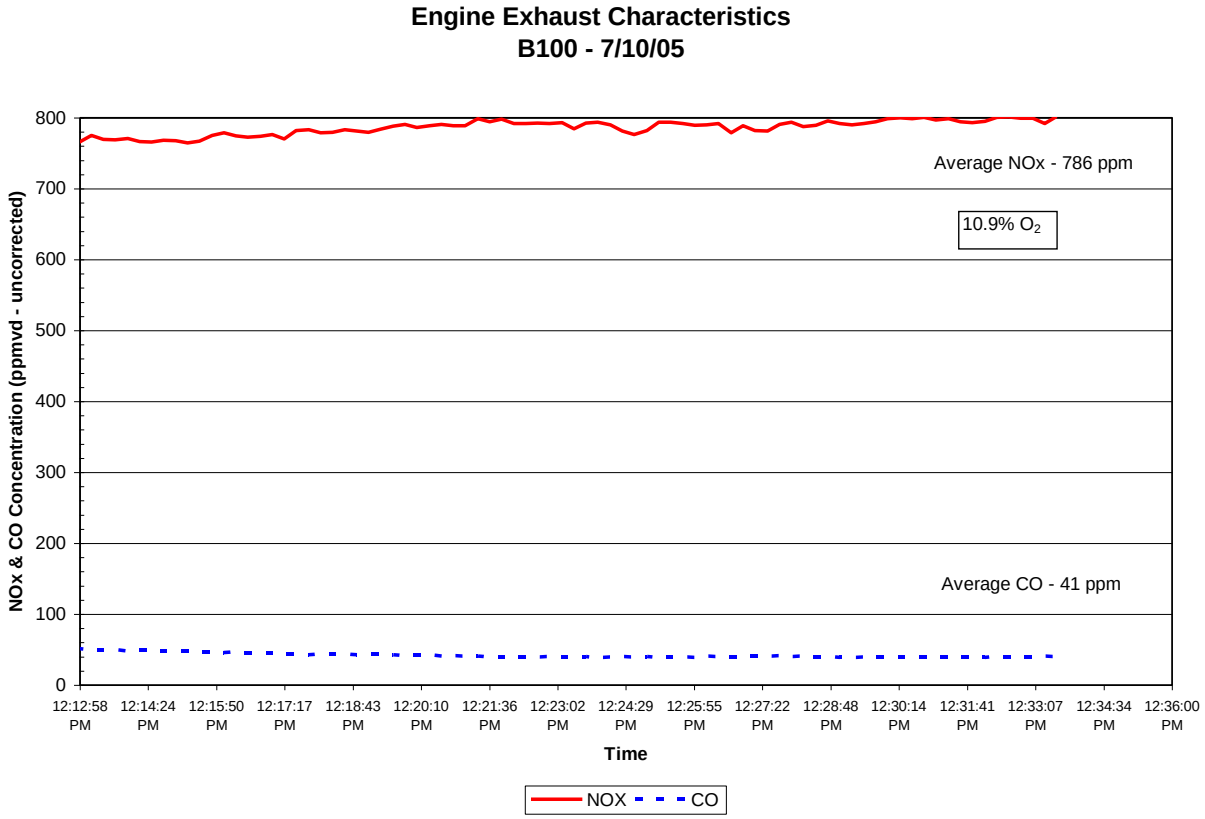


Figure IV-19

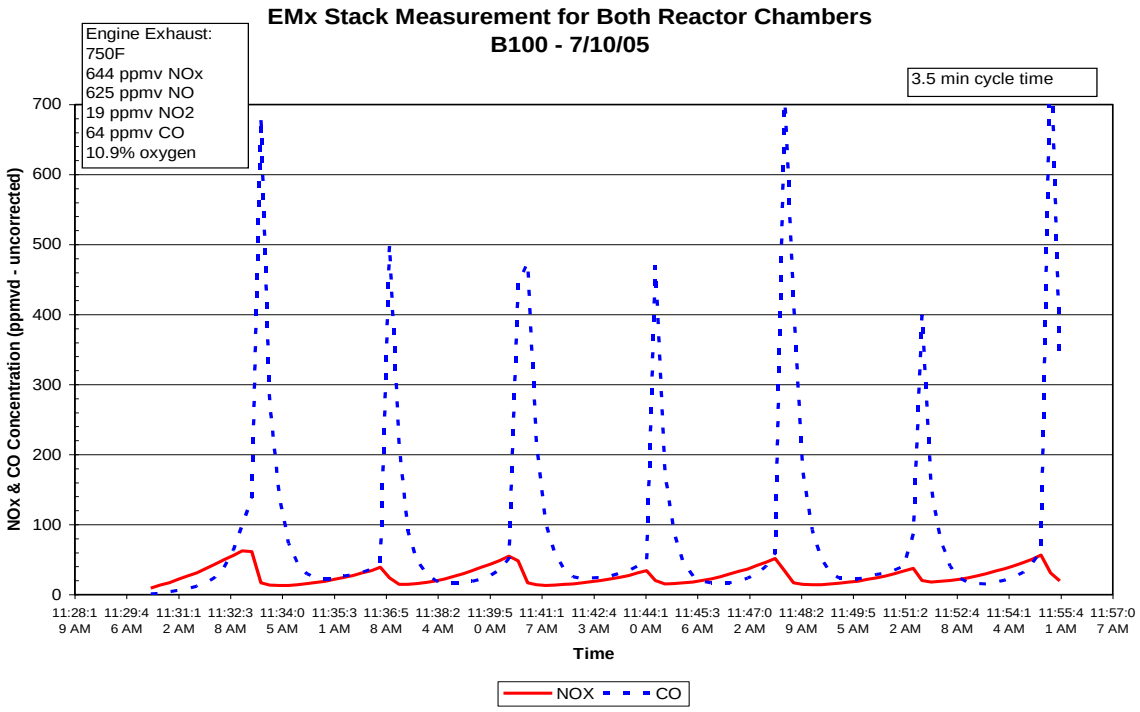


Figure IV-20

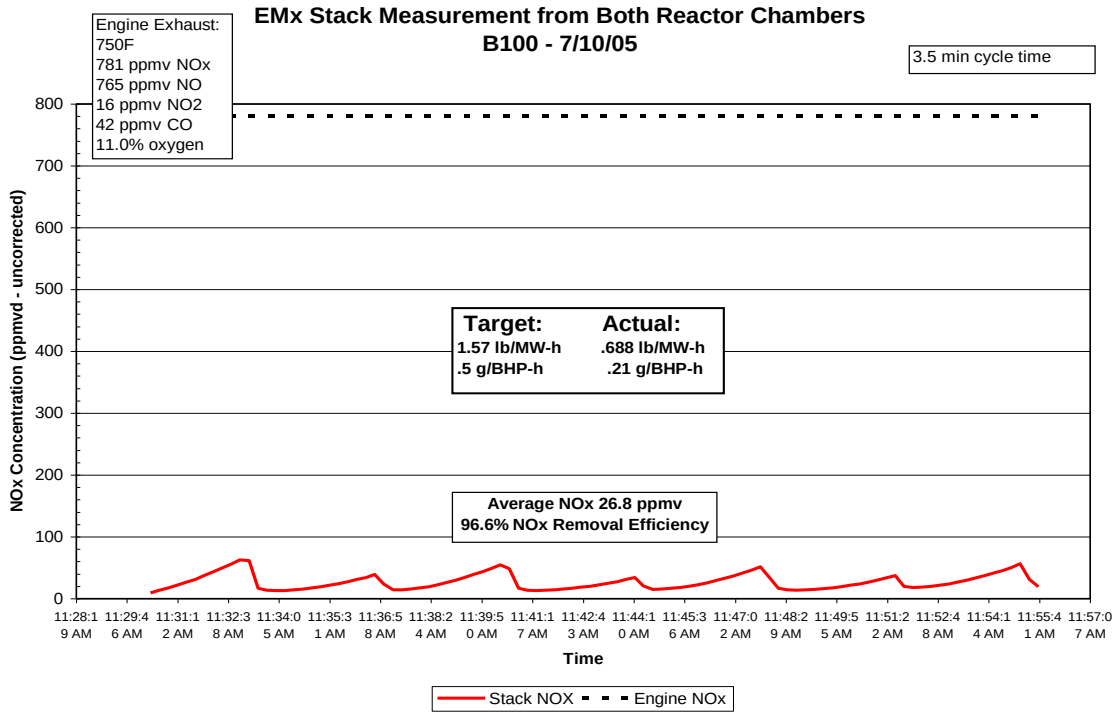


Figure IV-21

Fuel Affects

Figure IV-22 and **Figure IV-23** show the affect on engine emissions of NOx and CO when the engine is running various blends of ULSD and Biodiesel. In **Figure IV-22**, the effect is shown as a % change from pure ULSD fuel. In **Figure IV-23**, the NOx emissions (in ppmvd) are shown as measured before and after the catalyst. **Figure IV-24** shows the affect on regen gas composition when the plasma reformer is fueled by various blends of ULSD and Biodiesel.

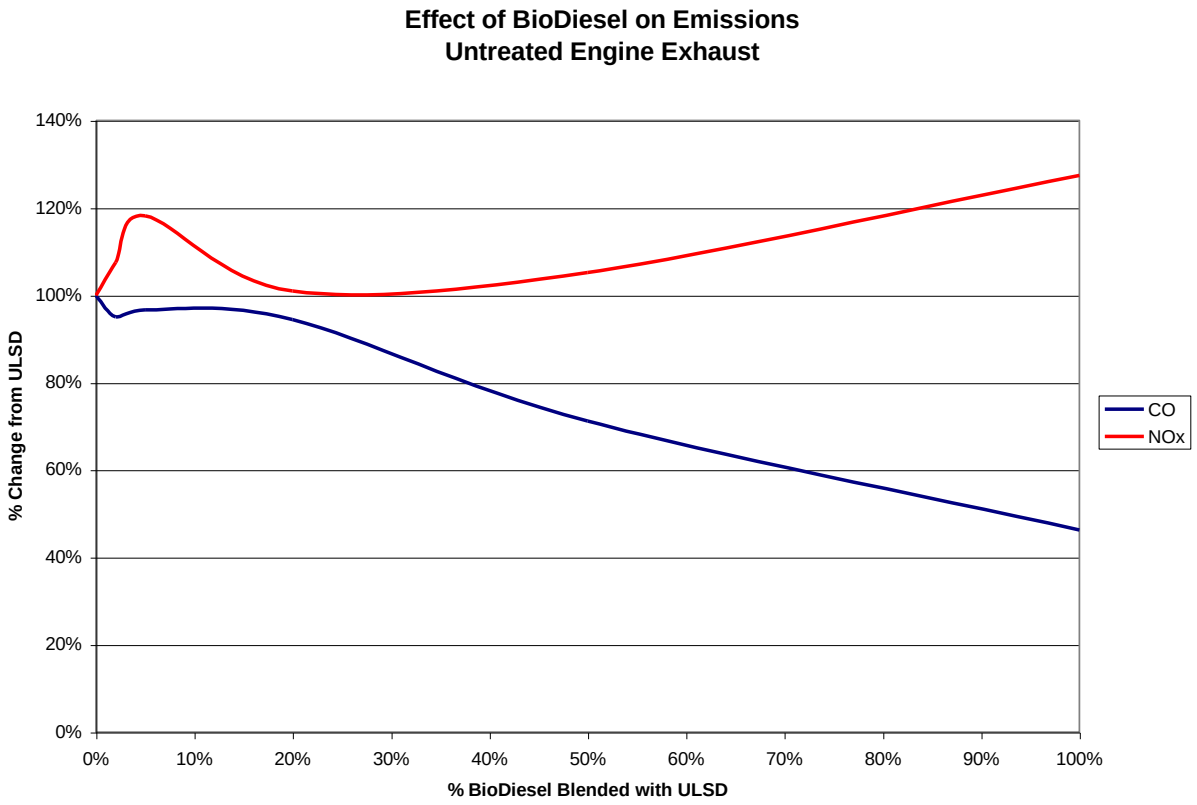
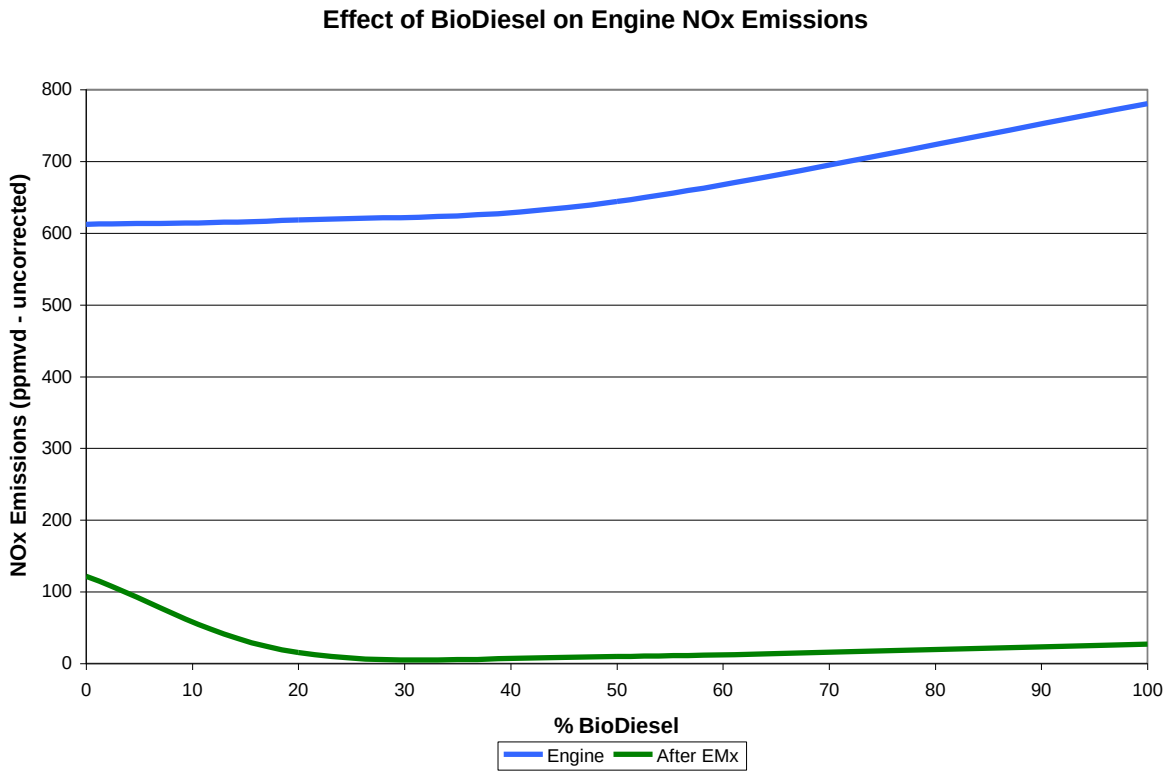
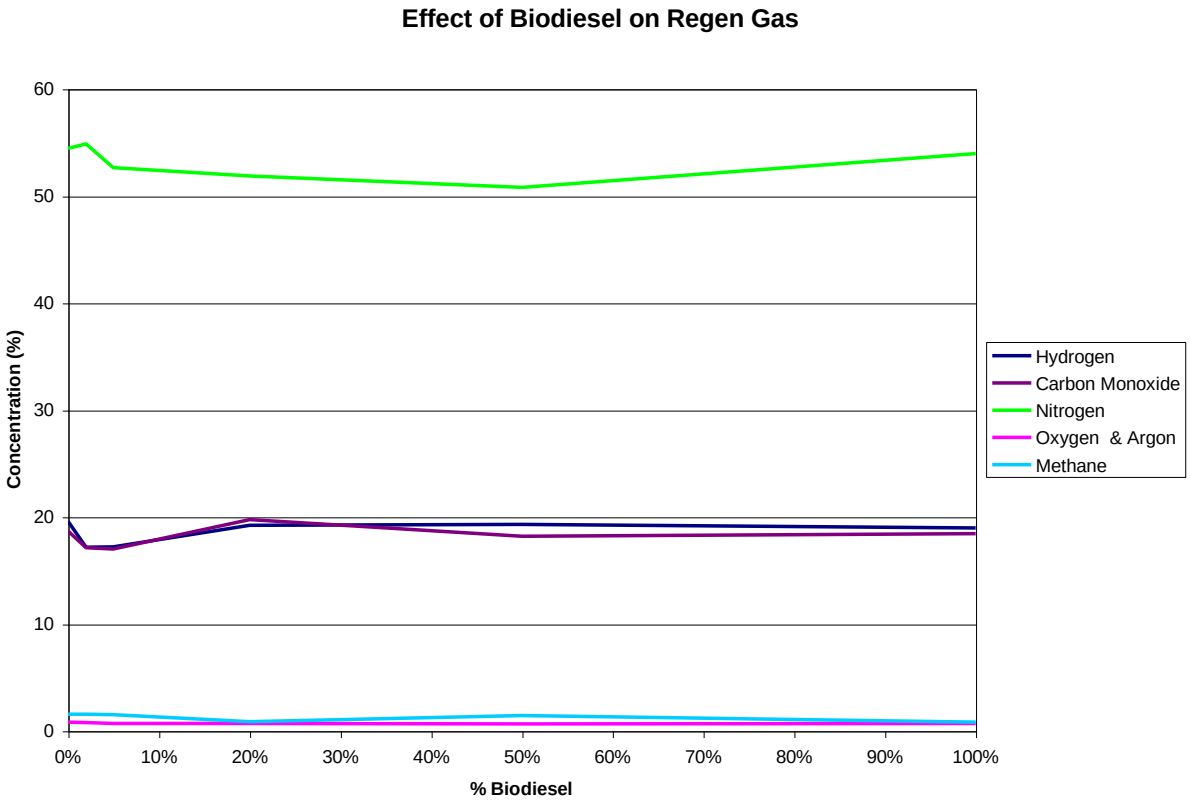


Figure IV-22



NOTE: Other variables were changed in addition to fuel type such as sorption cycle time, regen gas flow rate, etc.

Figure IV-23



NOTE: Other variables were changed in addition to fuel type such as operating temperature, water addition, air to fuel ratio, etc.

Figure IV-24

Long Term Test

Limiting Factors

Throughout the short term testing, the plasma reformer was not run for a full 24 hours. To achieve a 1500 hour run, this hurdle must first be crossed. After run 28, the EMx catalyst was removed from the system and never tested again. The entire demo program shifted to developing the plasma reformer. **Table V-1** and **Table V-2** summarize the plasma reformer runs completed in an attempt to accomplish this goal. Reliable, stable operation of the plasma reformer was not accomplished for periods longer than 30 hours.

Run	Date	Fuel	Duration (H:MM)	Reason Stopped	Comments
17	7/21/05	B100	0:58	Head leaking, replace gasket & re-tap bolts	Air in water line – short excursion to 1200 ˚C. Post-run inspection revealed no damage to Ni balls, electrodes, or thermowell. Applied high temp caulk, new grade 5 zinc coated steel bolts, trimmed damaged wires, re-connected ceramic connectors, trimmed damaged section of air line flex connection and re-attached, re-routed wires to avoid hot surfaces, bled air out of fuel and water lines.
18	7/22/05	B100	0:43	Air line leaking	Pre-heat flex hose leaking
19a	7/25/05	B100	2:49	Engine tripped	Engine fuel supply empty
19b	7/25/05	B100	5:17	Engine tripped	
21	7/26/05	B100	14:54	Low air flow	Air flow decreased from 21.6 scfm at 51 Hz at 7:04 to 18 scfm at 60 Hz at 21:21. Post run inspection revealed reformer full of carbon. Cleaned Ni balls, replaced granules
22	7/30/05	B100	0:33	Air line leaking	Pre-heat flex line leaking
23	8/4/05	B100	1:30	Temps too high	Temps too high for entire run. Water dripping at air inlet on lower side of reformer.
24	8/8/05	B100	3:58	Engine tripped	Installed new thermowell 2” deep in Ni balls. Right electrode wire burned through, arcing to center pipe.
25	8/9/05	B100	7:43	Low air flow	Air flow rates dropped from 21.6 scfm at 50 Hz at 10:45 to 18.2 scfm at 60 Hz at 5:40.

Run	Date	Fuel	Duration (H:MM)	Reason Stopped	Comments
26	9/21/05	B100	0:18	Liquids leaking around spark plugs	Tightened plugs but couldn't restart – both porcelain insulators cracked inside reformer, arcing to lid instead of electrodes. Replaced plugs, connectors, and sealed plugs with ceramic caulk.
27	9/22/05	B100	19:54 *Longest run to date.*	Low air flow	Targeting 4.9 air/fuel ratio and 900° - 1000° C per Dr. Tom Reed. Air flow rates dropped from 21.6 scfm at 50 Hz at 13:17 to 18.5 scfm at 60 Hz at 8:24. Engine shut down and went to flare at 9:50 to reduce backpressure. During this run, we used the temperature 1" above the reformer outlet as the control point, maintaining temperatures above 800° C minimum temperature to avoid the soot formation region described by Dr. Reed. This was the longest run to date, confirming the proper air/fuel/water ratios for soot-free operation. White/grey powder on Ni balls analyzed and determined to be due to minerals in water used for reformer. Demineralizer was installed before next run.
28	11/6/05 – 11/7/05	B100	30 hr *Longest run to date.*	Fuel filter plugged	As with run 27, we used the temperature 1" above the reformer outlet as control point. This was our most successful run, with extremely stable temperature and H_2 production. Air flow very slowly decreasing from 22.5 scfm at 50 Hz at 16:28 on 11/6 to 21.6 scfm at 52 Hz at 19:17 on 11/7. Fuel flow decreasing from 2.81 ml/s at 58% full stroke at 17:01 on 11/6 to 2.47 ml/s at 75% full stroke at 22:40 on 11/7. System left unattended after above adjustment. Overnight, fuel filter plugged, mixture went lean and overheated. By 6:30am, system was cool, air and water were still on at full flow.

Table V-1

At this point, the plasma reformer had suffered high temperature thermal damage. The reformer was completely redesigned and rebuilt with heavier gauge metals, more readily available components (e.g. spark plugs), larger internal capacities, and better fuel, air, and water mixing and atomization.

During run 28, measurements were taken to determine if the EMx system is still performing as it did in the early days of testing. **Figure V-1** shows the temperature profile inside the plasma reformer during runs number 27 and 28, the two most stable runs that were achieved.

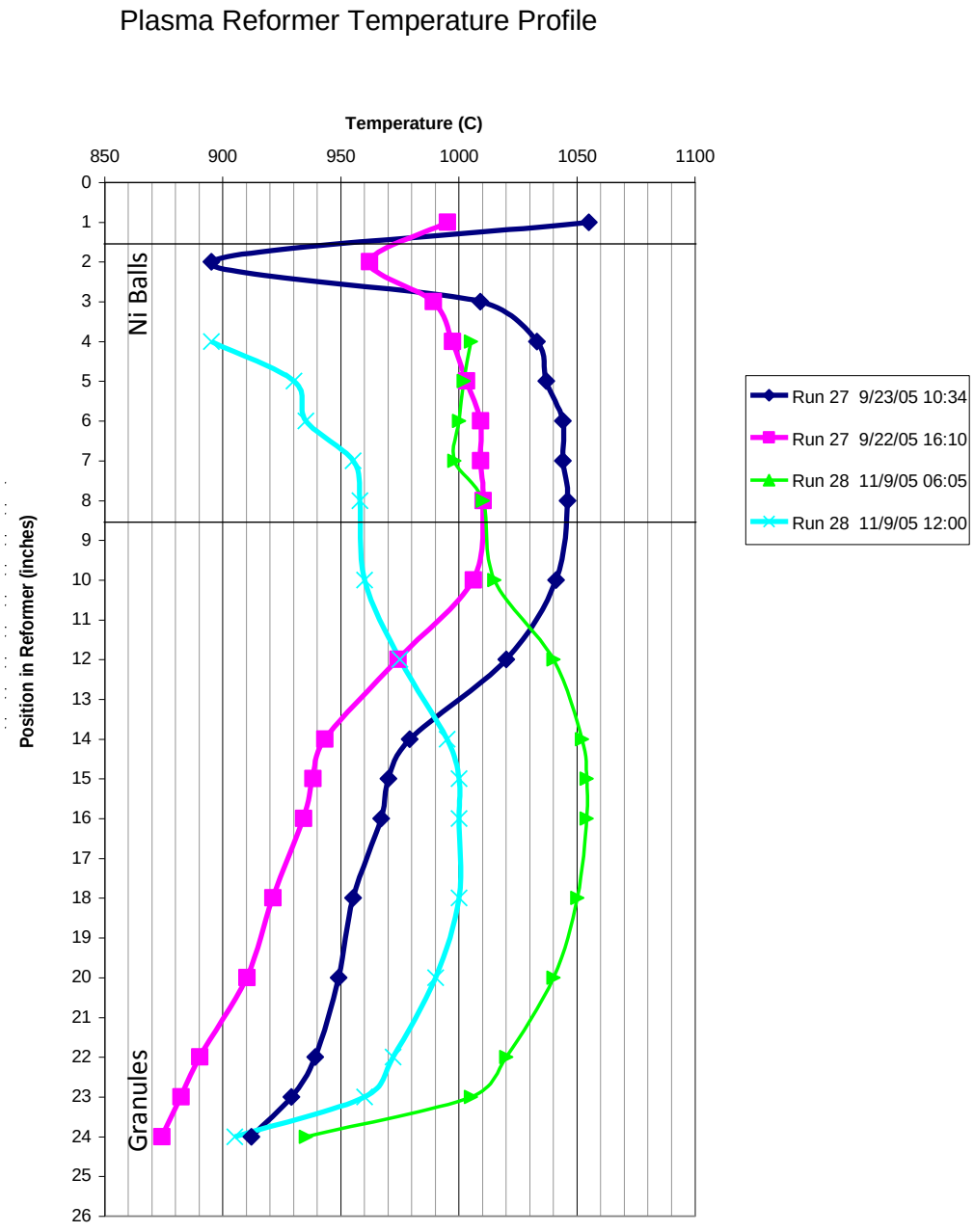


Figure V-1

Figure V-2 shows the oxygen depletion during run 28. The low minimum value indicates that there is little or no bypass around the catalyst modules. The amount of time that elapses before the minimum oxygen concentration is achieved is longer than in the tests run just after the catalyst and door seals were repaired. It is possible that the total regen gas flow rate is lower than during the earlier test.

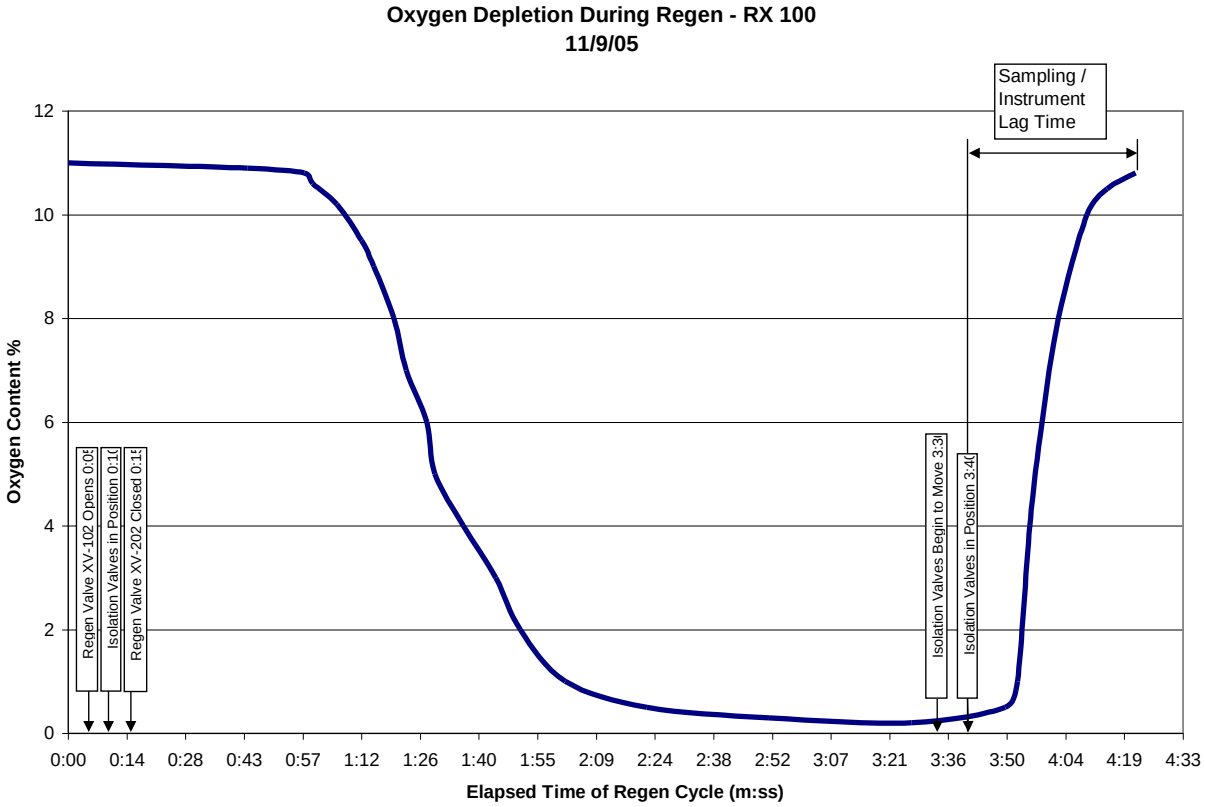


Figure V-2

After the catastrophic failure of the catalyst at the end of run 28, a new plasma reformer was designed as shown in **Figure V-3** and **Figure V-4**. The design included a thicker walled vessel, with off-the-shelf components wherever possible. All components were specified to be available in the United States, in contrast with the original design, which contained electrode connectors only available in Europe.

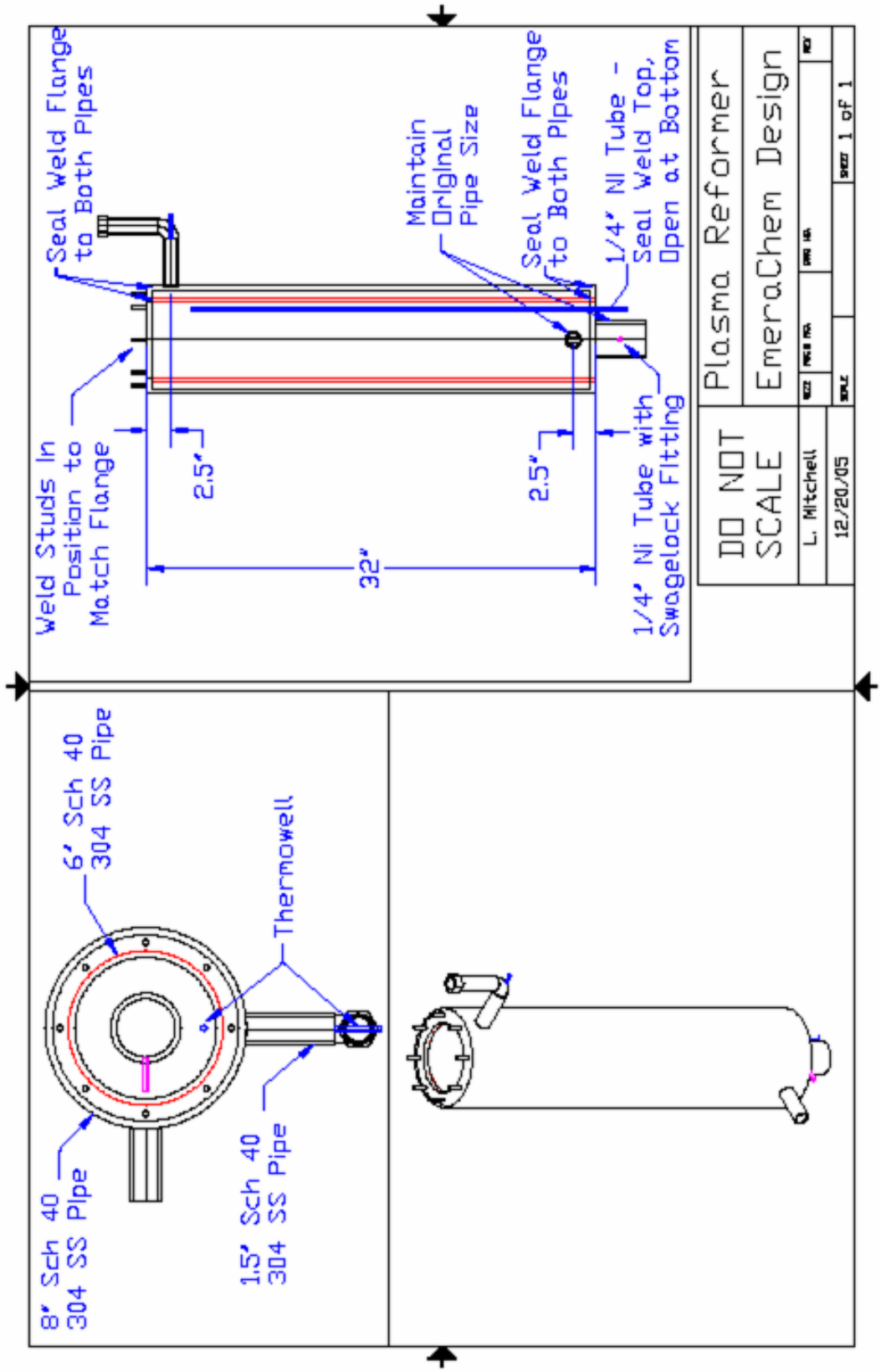

Seal Weld Flange to Both Pipes
Maintain Orlginal Pipe Size
Seal Weld Flange to Both Pipes
1/4" Ni Tube - Seal Weld Top, Open at Bottom
Weld Studs In Position to Match Flange
2.5"
2.5"
32"
1/4" Ni Tube with Swagelock Fitting
Plasma Reformer
EmeraChem Design
DO NOT SCALE
L. Mitchell
12/20/05
SHEET 1 of 1
6" Sch 40 304 SS Pipe
Thermowell
8" Sch 40 304 SS Pipe
1.5" Sch 40 304 SS Pipe

Figure V-3

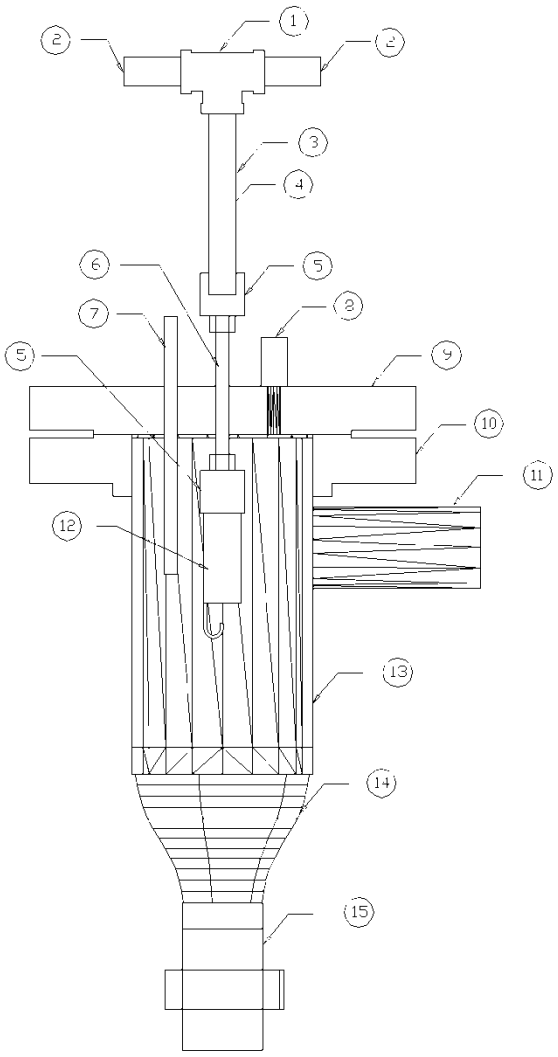


Figure V-4

Item	Qty	Description
1	1	316 SS Female Tee ¼" NPT x ¼" NPT (McMaster 4464K48)
2	2	316 SS Adapter ¼" NPT Male x ¼" YOR-LOK (McMaster 5182K111)
3	1	316 SS ¼" Pipe Nipple, Threaded 3 ½ " Long (McMaster 4548K144)
4	1	Static Mixer, 3 ½" Long
5	2	316 SS Adapter ¼" NPT Female x ¼" Tube Socket Weld (McMaster 51255K302)
6	1	316 SS ¼" Tube, Thick Walled
7	1	Thermowell
8	1	316 SS Adapter 1/8" NPT Male x 1/8" YOR-LOK (McMaster 5182K804)
9	1	316 SS Forged Type Blind Flange 3" (McMaster 44695K118)
10	1	316 SS Forged Type Slip-On Flange 3" (McMaster 44695K38)
11	1	316 SS 1 ½" SCH 40 Pipe
12	1	Bete 1/4P28@5 303 SS Fogging Nozzle
13	1	316 SS 3" Pipe Nipple, Threaded 1 End, 6" Long (McMaster 9110T79)
14	1	316 SS Reducing Coupling, 3" x 1" Butt-Weld x Butt-Weld
15	1	316 SS 1" Pipe Union, Socket-Weld x Socket-Weld

Run	Date	Fuel	Duration (H:MM)	Reason Stopped	Comments
29	10/9/06	B100	2:43	Unstable, not making hydrogen	First restart after complete rebuild of system. Larger vessel, larger diameter fuel and water lines, additional filter on fuel, additional filter on water, larger pre-heat air line, fuel/water mixing chamber installed with atomizer, no Ni balls – only untreated alumina balls
30	10/10/06	B100	Unknown	Temp spiked - 1343 ˚C	Very unstable. Max fuel and water reached, could not push one without restricting other. Temp spike was 10" into balls. Melted thermowell. Lid wedged onto studs, had to be pried off.
31	10/26/06	B100	0:59	Leaking fuel caught on fire	Oil leaking from mixing chamber onto lid. Max H2 – 14%, flare unstable. During cool down (very low air flow) H2 reached 22%. Temp higher in the middle of the reformer. Suspect air/water mixture was hitting walls and running down, resulting in worse atomization than original design
32	10/27/06	B100	1:23	Temperature spike to 1250 ˚C	Added ¾" layer of Ni balls to top of reformer and moved spray nozzle to mixer throat. Reformer lid gasket leaking, small leak between mixing chamber and reformer. H2 never above 8%, flare unstable, pulsating sound noted. Temperature climbed suddenly and rapidly to 1250 ˚C at 3" into the balls. Thermowell melted at 18" from bottom, Ni balls meted at top, ceramic balls slumped 1" below bridge of Ni balls. Ceramic balls free flowing. Nozzle black w/baked on carbon and tar.

Run	Date	Fuel	Duration (H:MM)	Reason Stopped	Comments
33	10/28/06	B100	~ 1 hr	Too hot - 1264 ° C at 18" from top of reformer.	Polished mating surface between mixing chamber and reformer to eliminate leaks. Replaced Ni thermowell and cut new gasket for reformer lid. Replaced spray nozzle and coated alumina beads with Ni salt prior to run. Very unstable hydrogen concentration – 4% to 18%. When more water is added, the fuel pressure goes up, resulting in lower fuel flow. Also, increasing water flow rate reduced temps at top of bed but greatly increased them in the middle of the bed. Suspect exothermic water/gas shift reaction is occurring inside the media.

Table V-2

After run 33, it was concluded that the plasma reformer instability had increased. Further progress will require extensive development efforts on the plasma reformer or an alternative source for regen gas. This may be due to the substitution of alumina balls for the fragile, but catalytically activated pumice stones, or the coating of the alumina balls with a nickel salt catalyst solution.

Conclusions

The EMx catalyst system performs at greater than 90% NOx removal, even with very high inlet NOx concentrations and operating temperatures of 750 ° F. The EMx system eliminates the visible plume and significantly silences the engine exhaust.

Summary of Results

1. NOx performance was high across all blends of biodiesel.
2. Exhaust bypass around the catalyst was discovered midway through the testing. This compromised several of the measurements made during commissioning and on the short-term fuel blend tests.
3. Unfortunately, most of the demo project focused on developing the plasma reformer, e.g., learning how to start up the system, how to operate it in a stable manner, how to avoid soot formation and high temperature extremes, how to retrofit it with safety interlocks, etc. Several design/rebuild retrofits were undertaken to improve the reliability of the reformer system and the durability of the hardware components. Ultimately, the plasma reformer proved to be unstable and unreliable and curtailed the studies of EMx performance.

Future Work

1. Future studies should include long-term studies of the effects of biodiesel on the catalyst.
2. All future studies hinge on the availability of reliable technologies to produce regeneration gas.

Attachment "C"

(The following report, which pertains solely to the Caterpillar 3516B genset, was commissioned by McMinnville Electric System as part of this Project and is therefore incorporated and made part of this Final Report as submitted. The author is unknown)

McMinnville Biodiesel Test

- Caterpillar 3516B EPG
  - Engine Built 8/20/04
  - 2293 BHP
  - 1640 Gen. KW @ 60 Hz (continuous)
  - Low Emission Strategy

Test Plan

- Blend B100 with Ultra Low Sulfur Diesel
  - 4 hrs on 98% ULSD and 2% B100
  - 4 hrs on 95% ULSD and 5% B100
  - 4 hrs on 80% ULSD and 20% B100
  - 4 hrs on 50% ULSD and 50% B100
  - Remainder of 1000 hr. test on 100% B100

(Continued)

- Sample oil every 100hrs (Dealer)
- B100 Fuel Sample prior to start-up (OK)
  - Lubricity (wear scar test @ 60C) tested at 0.169mm compared to a max. limit of 0.45mm
- 500 hr inspection
  - Return two injectors for analysis by Cat Fuel Systems
- 1000 hr inspection
  - Return two injectors for inspection (Cat Fuel Systems)
  - Return two cylinder packs (Cat)
  - Return two cylinder heads (Cat)

Miscellaneous Engine Information

- Fuel settings increased to compensate for B100. New settings allow engine to produce advertised horsepower
- Engine shutdown for winter with B100 in the fuel lines/injectors and started up w/o problems
- Totals
  - Hours 1007
  - Fuel Burned 108,966 gal.
  - Load Factor 88%

Injector Inspection/Analysis 500 Hours

- **Two injectors removed at 500 hrs.**
  - Two injectors were sent to Pontiac for verifying their performance after 500 hrs with bio-diesel. As shown above in the performance plots, Injectors performance is not significantly different from its original performance. Both the injectors were found to be low on delivery and timing. This small variation might be due to some debris clogged in the valve or the nozzle assembly. One of the injectors (S/n 642048) passed the performance test on retesting and another (S/n 642049) failed marginally for lower rated delivery only (D2 Vs T2 relationship).
  - As shown in Table 1 there was only 1% decrease in the rated delivery for injector with S/n 642048, which passed the test and there was 5.2% decrease in the rated delivery for injector with S/n 642049, which failed the test marginally but this is not a significant change.

Injector Inspection/Analysis 500 Hours (continued)

- **Summary**
  - Two injectors were submitted for general inspection after 500 hrs on engine with 100% biodiesel. Retest data is not significantly different from the original test data. One injector passed the performance test and one failed marginally for lower rated delivery as shown in the Figure 1 (D2 Vs T2 relationship). Rated as well as idle deliveries were on the lower side, which might be due to the flow restriction in the tips or bench movement.

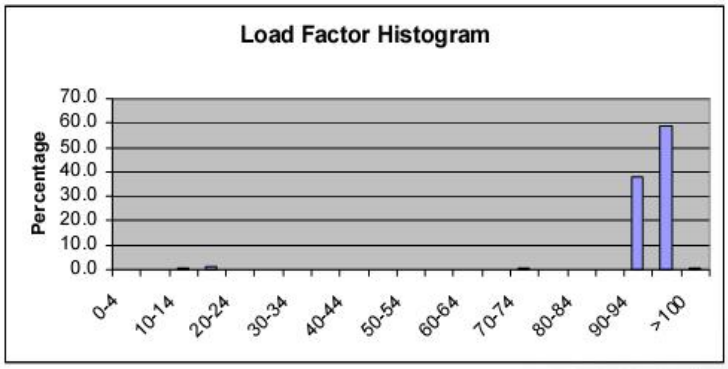
Injector Inspection/Analysis 1000 Hours

- **Two injectors removed at 1000 hrs.**
  - Two injectors were sent to Pontiac for verifying their performance after 1000 hrs with bio-diesel. As shown above in the performance plots, Injectors performance is not significantly different from its original performance. Both the injectors were found to be low on delivery and timing. This small variation might be due to some debris clogged in the valve or the nozzle assembly. As shown in Table 1, one of the injectors (S/n 642053) passed the performance test on retesting and another (S/n 642058) failed for leak, which is marginally out of the limit and which could be a bench error.
  - Inspection:
  - All the injector parts were inspected thoroughly under magnification and as show in the figure below, there is no sign of cavitation or unusual wear on the critical injector components.

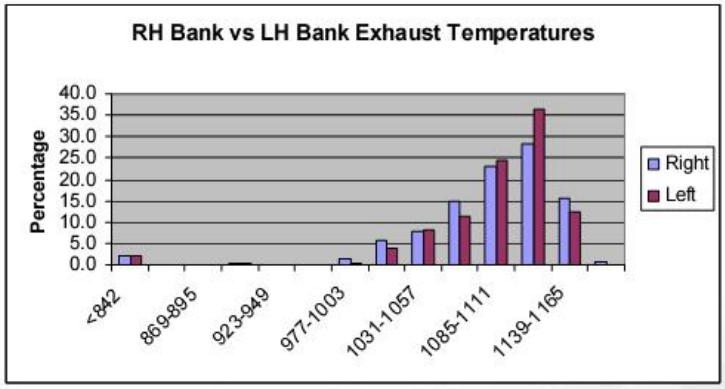
Injector Inspection/Analysis 1000 Hours (continued)

- **Summary**
  - Two injectors were submitted for general inspection after 1000 hrs of operation with 100% biodiesel in the engine. One injector passed the performance test on retesting and one failed marginally for leakage. Performance results are not significantly different from the original test data. Rated as well as idle deliveries and timing are on the lower side, which might be because of the flow restriction in tips due to debris. This was also seen in the 500hr test returned injectors for inspection with 100% biodiesel (See report 075-010807).

Load Factor Histogram



Exhaust Temperature Histograms



Logged Diagnostic Codes

Code	Description	Occur	First	Last
3516B Eng - Genset #1 (1HZ02868) - Diagnostic Clock = 1007 hours				
94-11	Fuel Delivery Pressure Sensor : Other Failure Mode	6	965	989

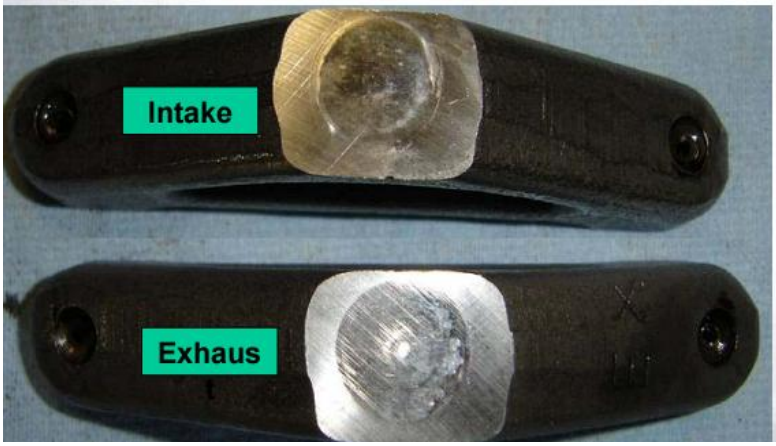
Issues Identified at 1000 hr. Inspection

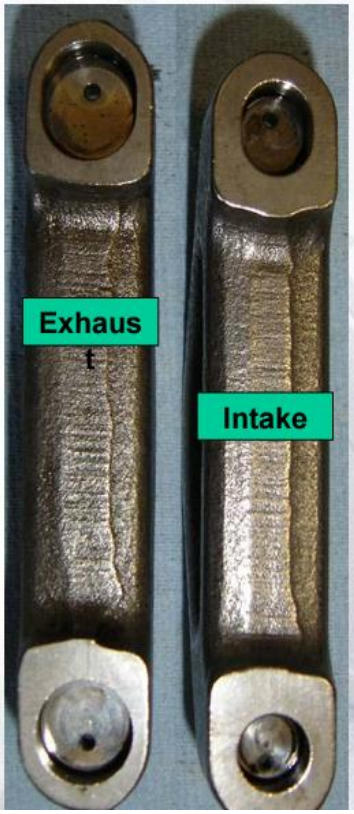
- Items negatively affected by B100
  - Lower cylinder liner seals
  - ECM fuel cooling hoses
  - Fuel cooler hoses
  - Oil cooler outer tube seals
  - Engine oil samples
- Issues not related to B100
  - Right hand bank wet stacking

Summary

- No downtime due to engine
- Internal moving components in excellent condition
- Hose/seal material acceptable for <B30, needs to be modified for operating on B100
- Test was very successful

Floating Bridges





Rocker Arms

Exhaust

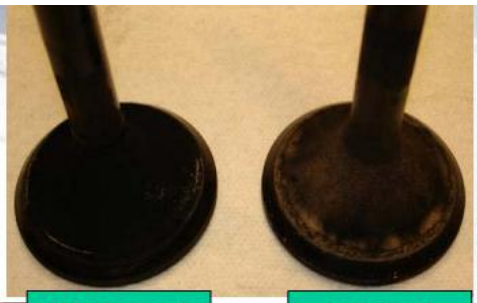
Intake

Injector

Injector

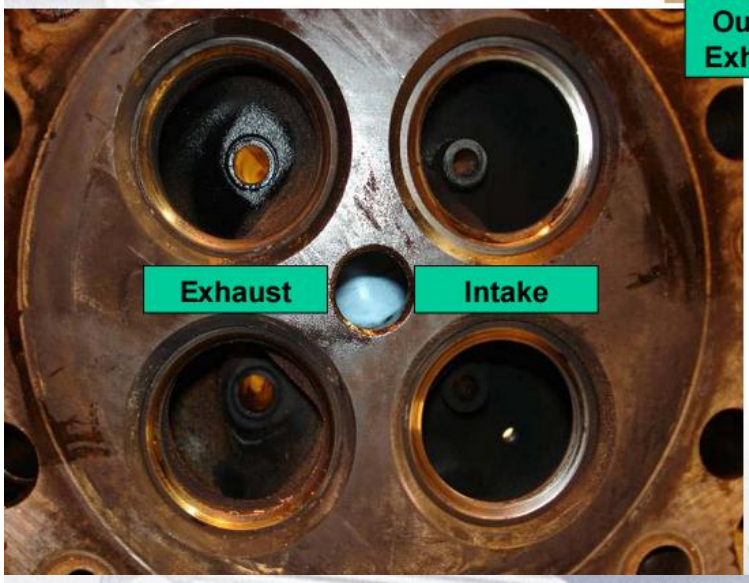
Injector tip oily but no performance issues

Cylinder Head



Outboard Exh. Valve

Inboard Exh. Valve

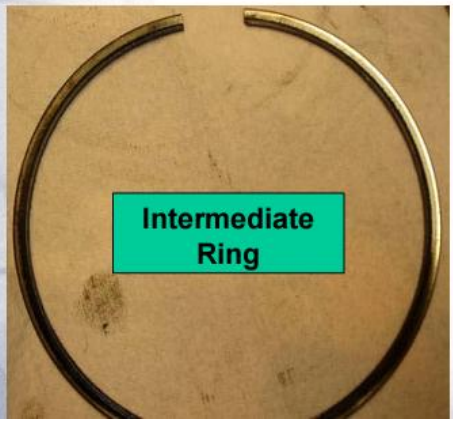


Piston

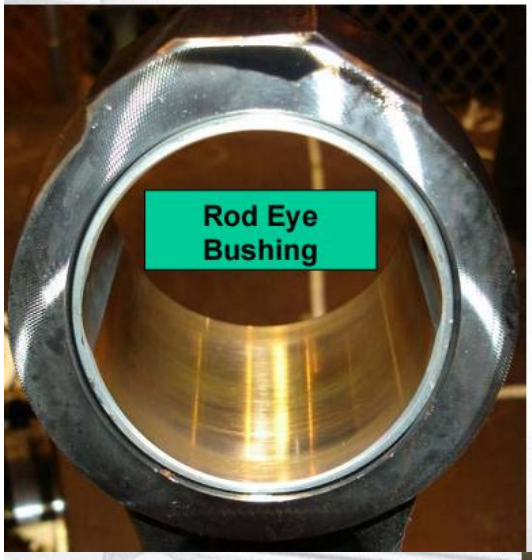
Piston

(continued)

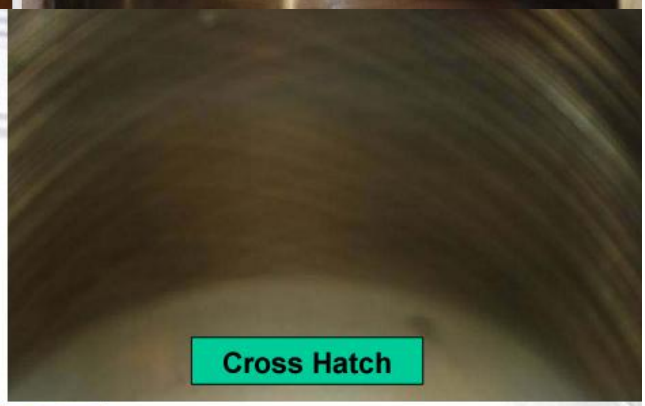
Rings (Continued)

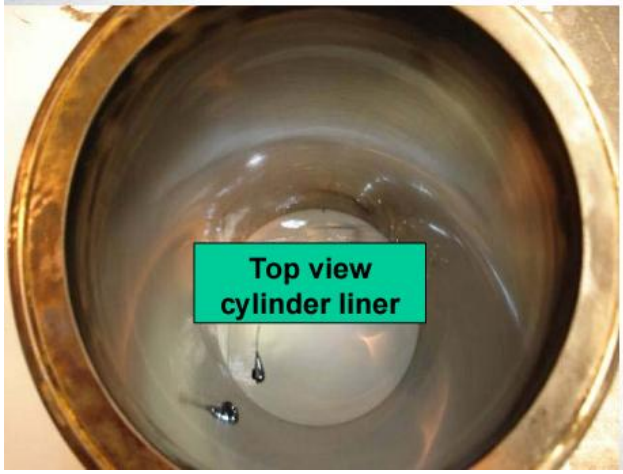


Connecting Rod

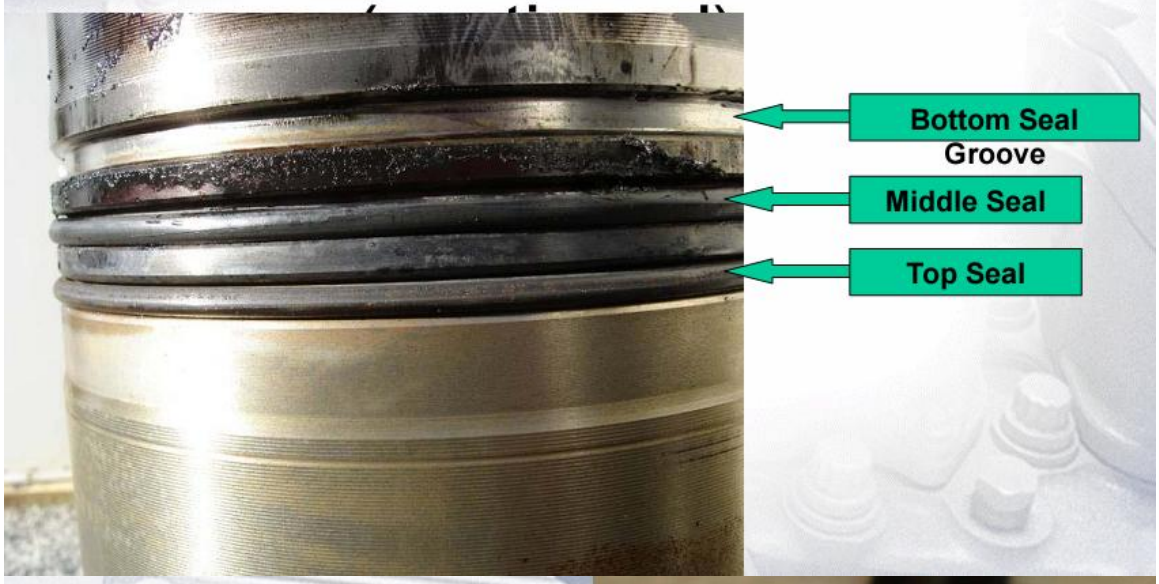


Cylinder Liner

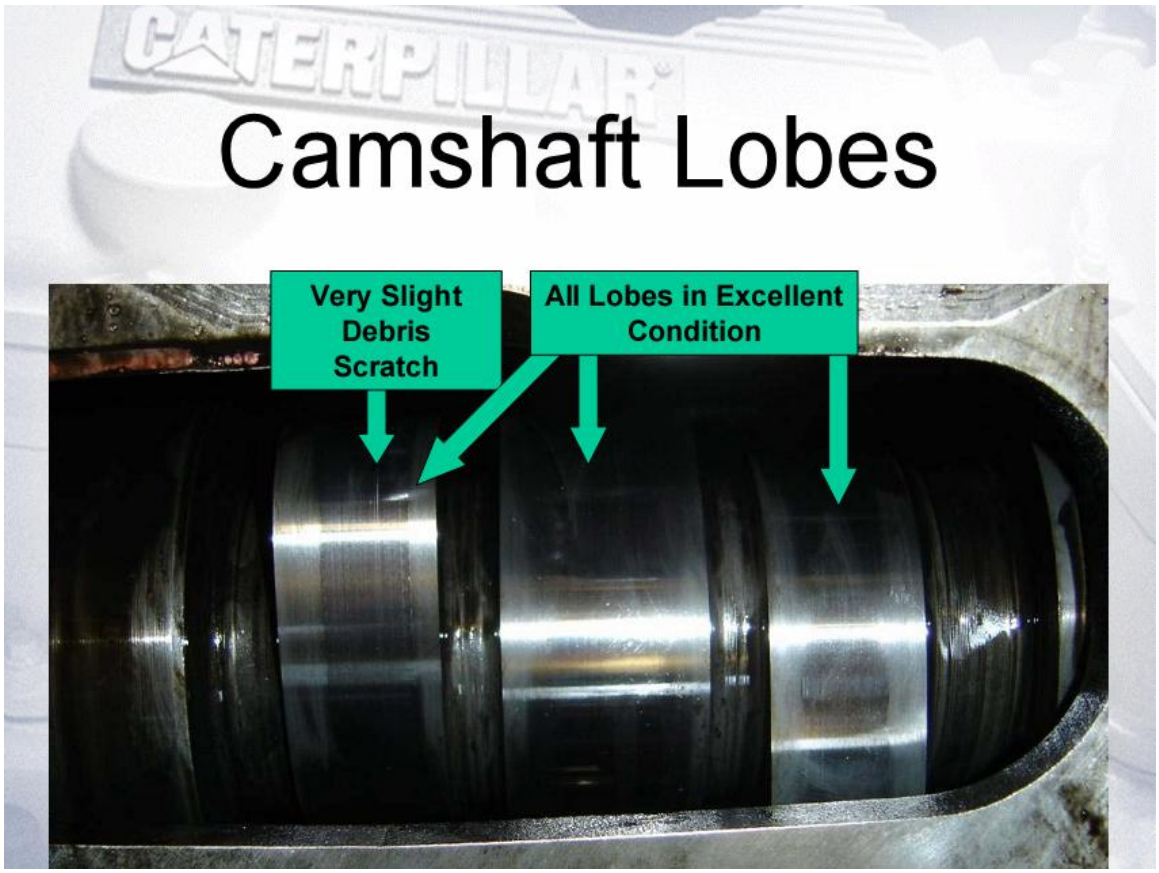




Cylinder Liner



Cylinder Liner (continued)


CATERPILLAR
Camshaft Lobes
Very Slight Debris Scratch
All Lobes in Excellent Condition

Attachment "D"

GENERATION OF 1 kg/h OF HYDROGEN FROM SOYBEAN BIODIESEL

A. Czernichowski, M. Czernichowski and K. Wesolowska

ECP - GlidArc Technologies, 45240 La Ferté Saint Aubin, France

Introduction

Efficient and non-sooting conversion of carbonaceous feeds into the SynGas (a mixture containing H_2 and CO) still remains at the R&D stage. We believe that the Partial Oxidation (POX) process assisted by our GlidArc plasma is the best way of Syngas production. It uses an internal heat generation *via* low- or high-temperature combustion of a part of the feed in order to raise the temperature to a level where the POX can be done. At sufficiently high temperature it does not ask for complex, fragile and expensive catalysts.

Two US companies have been interested in our plasma-assisted technology to check if such biodiesel-into-SynGas converter, gas product flow rate, and gas quality can be used as a:

a) Part of de-NOx process in which frequent catalyst regeneration using Hydrogen is required,
b) Gaseous fuel to feed (or only boost) ordinary engines (ICEs) for decentralized power generation.

ECP has accepted both challenges and accordingly we built three prototypes of such reformers of 100% soybean biodiesel. Two prototypes installed in Tennessee and Colorado were successfully tested last summer and fall, respectively.

GlidArc-assisted reformer

The principle and a picture of our two-zone POX reformer are presented in two parallel papers on biomethane reforming[1] and on bioethanol processing[2]. Our GlidArc discharge (see Fig. 1) is inserted in a plasma-assisted zone of the reformer.

Figure 1. GlidArc discharge between two flat electrodes in air.

This zone communicates with the second zone filled with activated refractory granules where the fuel conversion is completed. A 10-kV supply provides both an ionization of the oxidant/fuel mix and then a transfer of the electric energy into the plasma. The electric power measured at the mains is 0.5 kW as maximum for almost 80 kW output SynGas power (based on its Lower Heating Value, LHV). The reformer is thermally insulated to keep the post-plasma zone hot. It also contains a double wall in which air is preheated. Total inside volume of our reformers reaches presently 6 L. Some thermocouples measure the post-plasma zone temperatures. Almost all SynGas is immediately flared during the laboratory trials or sent to an application like here presented de-NOx catalyst regeneration or an ICE feeding. A sample of SynGas crosses white wool for soot presence check. Other sample is analyzed using a two-channel μ-GC dedicated to H_2, O_2, N_2, CH_4, CO, CO_2, C_2H_4, C_2H_6, C_2H_2, C_3H_8+C_3H_6, and residual moisture.

Reforming

Feed. Soybean biodiesel used for our tests in France presents the LHV of 10.4 kWh/kg and a chemical formula $(CH_{1.87}O_{0.11})_n$. Atmospheric air is used as oxidant. No air-drying is applied.

Chemistry. An ideal POX process of biodiesel conversion into SynGas using air can be written as:

$$CH_{1.87}O_{0.11} + 0.445\ O_2 (+ 1.68\ N_2) = CO + 0.935\ H_2 (+ 1.68\ N_2). \quad (1)$$

It would ask for 3.05 Litres [at normal (n) conditions] per gram of biodiesel. Unfortunately, such reaction cannot be realized, as the Thermodynamic prefers to form rather methane CH_4 and soot to find its deepest Gibbs energy level. To suppress these unwanted products one needs to add more Oxygen (from air in this case) that will highly rise the temperature of the process and produce other unwanted (but more acceptable) products: CO_2 and H_2O. To simplify one can write a parallel full combustion reaction:

$$CH_{1.87}O_{0.11} + 1.41\ O_2 (+ 5.32\ N_2) = CO_2 + 0.935\ H_2O (+ 5.32\ N_2) \quad (2)$$

that asks for 9.65 L(n) of air per gram of biodiesel.

As result one can consider such non-sooting conversion of the biodiesel as a mix of the reactions (1) and (2) in a proportion of "*x*" moles of biodiesel completely burnt according to the reaction (2) per one mole of biodiesel converted according to the reaction (1). Some steam is already produced by the reaction (2). Adding extra water we promote the water-shift reaction:

$$CO + H_2O = CO_2 + H_2 \quad (3)$$

as well as other endothermic processes of soot gasification and methane Steam Reforming (SR) like:

$$CH_4 + H_2O = CO + 3\ H_2 \quad (4)$$

so that the value "*x*" can be diminished.

Our GlidArc-assisted process can therefore be considered as Compromise between an ideal POX, full combustion and SR processes in the presence of a contact surface. Our very simple cold plasma source ignites these processes and keeps them progressing through an injection of highly activated catalytic species.

Experiments in ECP's facility. An industrial blower at the input pressure up to 370 mbar provides air. The air flow at variable rates is set in a function of the variable fuel flow rates that define a wanted output SynGas flow. Air enters the double-wall of the reformer where it is preheated in order to integrate a waste process heat for better thermal efficiency of the reforming. A pump sucks biodiesel the from a recipient put on a scale. Water directly taken from the water-supplying pipe is injected to the reformer through the same injection pipe that we use for the fuel. The following ranges of parameters and conditions are explored:

Air input flow-rate L(n)/min	137 - 464	
Biodiesel oil flow-rate	29 - 150	g/min
Water flow rate	21 - 75	g/min
Input power (LHV) of fuel	18 - 94	kW
Air/fuel ratio	3.1 - 5.2	L(n)/g
Water/fuel ratio	0.47 - 1.1	g/g

As results we are generating the SynGas containing the following species (dry, in vol.%):

H_2	19 - 23 (av. 22)	CO	10 - 20 (av. 15)
H_2+CO	29 - 43 (av. 37)	N_2+Ar	48 - 60 (av. 53)
CO_2	6.7 - 11 (av. 8.5)	CH_4	0.5 - 1.5 (av. 0.9)
C_2H_4	0.05- 0.25	C_2H_6	0.02 - 0.05

[1] Czernichowski, A.; Wesolowska, K. Prepr. Pap. - *Am. Chem. Soc., Div. Fuel Chem.*, **2006**, *51 (2)*.
[2] Czernichowski, A.; Wesolowska, K. Prepr. Pap. - *Am. Chem. Soc., Div. Fuel Chem.*, **2006**, *51 (2)*.

O_2, C_2H_2	absent	C_3	0 - 0.003

From the mass balance we calculate the following:

Output of H_2 + CO (accounted as pure)		64 - 329 L(n)/min
Output Syngas Power (LHV)	13 - 73	kW
H_2 + CO output efficiency	2.0 - 2.2 (av. 2.1)	L(n)/g
H_2/CO ratio in SynGas	1.2 - 2.3 (av. 1.5)	mol/mol)

Figures 2 and 3 present some results of the biodiesel reforming. No soot is observed.

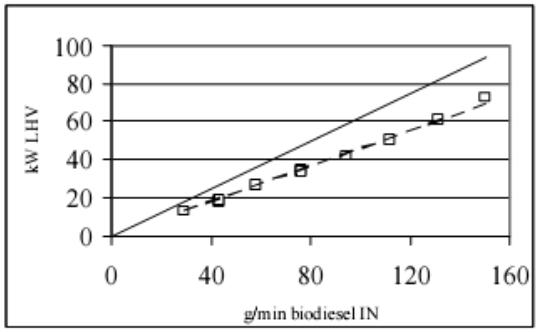


Figure 2 Output SynGas power (points) and input biodiesel power (solid line) as the function of the fuel input flow-rate. The ratio of two line slopes indicates a 74% averaged thermal efficiency of our reforming.

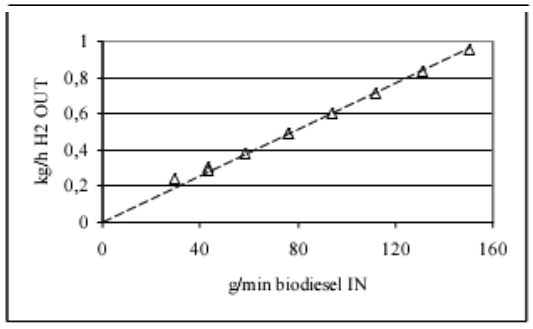


Figure 3. Generated Hydrogen output flow rate as the function of biodiesel input flow-rate.

Application: Large-scale de-NOx. After first concluding tests in our facility, one of the reformers was installed in McMinnville (TN) peak power station where the full-scale tests of NOx removal from an engine exhaust were performed in July 2005, see Fig. 4. Our partner installed there its prototype of the full-scale exhaust gas cleaning from a 4-MW Caterpillar Diesel engine. Specific de-NOx operation is based on a catalytic process requiring frequent catalyst regeneration by Hydrogen. As the Diesel engine was driven by 100% Soybean biodiesel derived, the evident choice of the primary feed to generate Hydrogen-containing gas for the catalyst regeneration was the same fuel. Under an independent control (TNA) our partner and ECP have successfully demonstrated the feasibility of the full industrial-scale cleaning of the whole exhaust of this engine. In fact the NOx concentration in the engine exhaust gas was reduced by more than 96% to a very acceptable level of about 30 ppm. Also all other characteristic of the exhaust have passed successfully the TNA regulation so that the local electric power station can apply to produce more electric power based on renewable biodiesel.

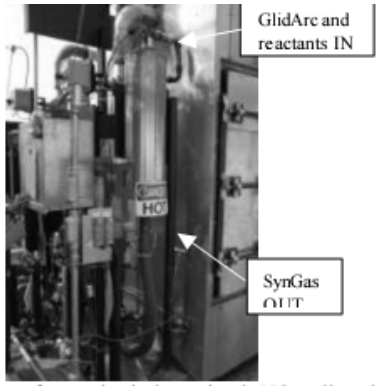


Figure 4. ECP's reformer hooked on the de-NOx pilot plant capable to remove 96% of NOx from 4MW engine fuelled by biodiesel. The reformer generates continuously 1 kg/h of Hydrogen gas from the same biodiesel for cyclic de-NOx catalyst regeneration.

Application: Fueling of an ICE. Another copy of ECP's reformer is tested in the Renewable Hydrogen Foundation (RHF) in Golden, CO. The goal of this demonstration is to show the feasibility to supplement the grid of a rural electric cooperative using a classical spark-ignited ICE running on the SynGas produced from biodiesel. Such installation will help to supplement the grid by producing 5 – 30 kW at the peak periods. While this is a small project, it intends to demonstrate the ability of our united technologies to cover peak usage and to provide an economic benefit. Powering a spark engine with biodiesel would be a great step on the way to practical alternative fuels and their use within the USA current infrastructure.

In November 2005 we started testing the biodiesel reforming using ECP's reformer shown on Fig. 5. First, a 24-hours continuous run was successfully performed while whole generated SynGas was flared outside. After this run we dismantled the reformer and did not find any trace of soot. Then a spark-ignited engine ran several times using the reformed biodiesel. The maximum RPM value for the engine during the test was 3500. That was the maximum flow rate of biodiesel that current valve set up would allow.

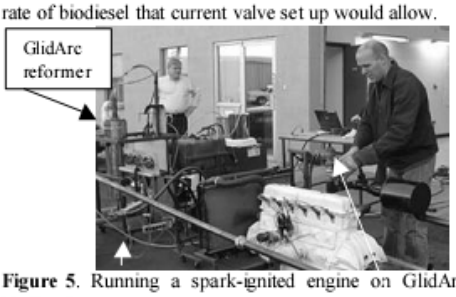


Figure 5. Running a spark-ignited engine on GlidArc-reformed biodiesel.

Second component of our project is research on reforming of raw vegetable oils. On November 28, 2005 RHF has successfully ran an engine on reformed soy oil; to our knowledge this is the first time that has been done. Hopefully, we will have a minimally modified, typical car or hybrid car running on Hydrogen from such oils. The Rapeseed oil conversion to SynGas was already successfully tested[3] as an example of various renewable oils processing.

[3] Czernichowski, A.; Czernichowski, M.; Wesolowska, K. *Hydrogen and Fuel Cells Conf. Vancouver, Canada*, **2003**, CD proceedings, 8 pp.

Attachment "E"

Further development of plasma sources: the GlidArc-III

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ECP – GlidArc Technologies, La Ferté St Aubin, France

Abstract
A 45 years story of construction and development of various plasma sources for various applications is presented. It starts with a stabilized low-voltage but high-current intensity DC free-burning arc, a typical example of so-called "thermal plasma". Nowadays, we rather prefer our completely unstable AC high-voltage and very low-current plasma sources called "GlidArc". Third generation of this low-cost (and low-tech) devices is under development.
Keywords: GlidArc, plasma sources

1. Introduction

Since 46 years the first author has been involved in construction and/or development of various plasma sources for chemistry, metallurgy, atomic and molecular spectroscopy, deposition, assisted partial- or full-oxidation, and other. Under direction of Professor Wlodzimierz Trzebiatowski he started in 1959 with a DC free-burning low-voltage arc (up to 1500A in Argon) as a high-temperature source for some refractory minerals decomposition in Wroclaw's Technical University, Poland. Then he has successively built the first Polish DC plasma torch (1960) and started a study of the Argon plasma spectral emission. In 1962 he switched to an 800A DC arc in water- or Nitrogen-swirl; these plasma reactors were used for the Iron Titanate and Zirconium Silicate processing (Ph.D. thesis in 1966). Successively came a new DC torch having a Tungsten cathode and a segmented Copper anode (each segment actively power supplied at various electric potentials) for SiO_2, TiO_2 and ZrO_2 reduction in Hydrogen (1970). In turn a microwave torch for NO_x synthesis (3kW, 1973), an arc striking to the molten LiCl (1974), an induction-coupled torch (atmospheric pressure, 25kW, 1975), a metal-wall-stabilized arc for plasma spectroscopy (150A, 1975), a multiple-electrode and high intensity rotating/pulsating arc (1980), an unstable and very active transferred DC arc for Hydrocarbon or H_2S processing (1983), a high current circuit breaker (1983), an electro-burner for Methane flame over-heating (1985), and a semi-industrial 250kW DC transferred arc furnace (1987) took his attention…

In early 1980's the plasma-chemical community started to abandon the so-called "thermal plasma" devices for chemical applications, as it appeared that their high electric energy consumption cannot be accepted for most of industrial processes. Also the microwave and induction-coupled sources did not get a large approval because of their complex electric supplying, especially for higher power units. Other non-thermal ("cold" or "out-of-equilibrium") plasmas were demanded… Accordingly, the gliding arc device was proposed in 1988 [1]; it is now known under its short name "GlidArc".

2. Gliding Discharges

2.1. GlidArc-I

The GlidArc generates non-thermal plasma that enhances various processes through active catalytic species: electrons, ions, and excited atoms. This source has at least two diverging electrodes immersed in a fast gas or vapour flow. A high voltage and relatively low current discharge (up to 30kV, 0.05-5A, 0-20kHz) is generated across the flow between the electrodes as it is shown on the Fig. 1. The discharge forms at the closest point between the electrodes, glides along the electrode's edges, and disappears. Another discharge immediately reforms close to the initial spot. The discharge performs its own maintenance on the electrodes, preventing chemical corrosion and/or thermal erosion. The electrodes are not water-cooled so the electric power is directly and totally transferred to the processed feed. Any gas or vapour can be directly processed at 0.05-12bar range. Droplets, mists, and powders can be present. Feeds of any initial temperature are accepted.

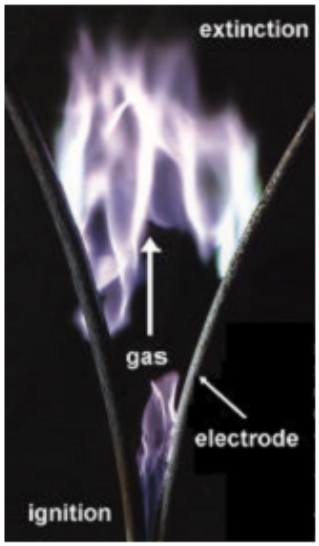

Fig. 1. The GlidArc-I

Gliding discharges of GlidArc-I type can be also installed between metallic electrodes and a conducting liquid [2]. Multiple electrode systems can be installed for large gas steams processing. Their electric powering is described in [3]. Structures of several dozens of electrodes can be organized as "clusters" forming some plasma heads for powerful AC plasma reactors supplied from unique 3-phase transformer [4].

2.2. GlidArc-II

In 1996 we started to develop an alternative way of gliding discharges generation using a rotating central electrode and "connecting" it, *via* high-voltage AC discharges, to several stationary electrodes located around the central electrode [5]. As result we have obtained a new GlidArc-II device. Figure 2 presents the principle of such cold-plasma source while the Fig. 3 shows a principle of multiple-stage reactor in which the processed fluid can cross several electric discharges to reach a suitable rate of conversion.

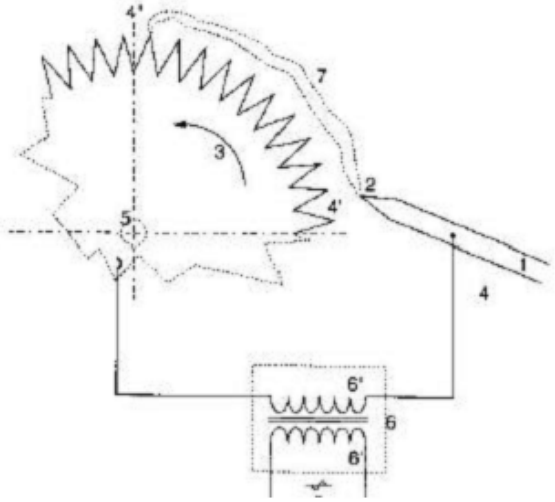

Fig. 2. Principle of the GlidArc-II device: 1 – stationary electrode, 3 – rotating electrode, 6 – power supply, 7 – high-voltage discharge filaments.

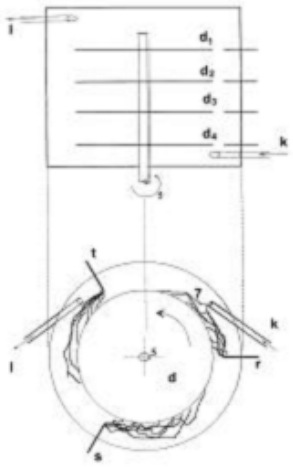

Fig. 3. Multiple-stages and multiple-electrodes GlidArc-II reactor: r, s, and t – three-phase-supplied stationary electrodes, k and l – input and output of the processed gas, d – rotating electrodes.

There are multiple advantages of the new structure. The high voltage discharges generation and the processed gas flow rates are no more self-dependent so that even a very low gas flow can now be accepted at any power as there is no more need to accelerate the gas at the proximity of electrodes. The mobile electrodes rotate in the range of 50–1000rad/s, which are acceptable speeds. The discharges can "touch" several times the same gas flux without any obligation to push the gas between the stages. The reactor is quite compact for even large gas flows. For example one can realize three 5A and 2kV discharges for one stage. When adding 4stages it makes us a 120kW reactor realized in a 0.3m diameter cylinder of 0.5m length (30L of volume). Such reactor can process roughly up to 2400 m^3/h of gas.

A 60-L stainless steel reactor was built by ECP for H_2S-related streams processing. This reactor presented on the Fig. 4 contains 9stages, each of them being powered by 3 stationary electrodes so that 36 active electrodes are present (including central electrodes).

First successive tests of this reactor were performed with an active participation of Piotr Czernichowski. We have obtained better than 50% conversion of an H_2S-rich acid gas into the SynGas.

Fig. 4. 60-L, 36-electrodes GlidArc-II pilot plant for Hydrogen Sulphide processing (SulfArc).

Several application tests and studies were performed in laboratory or pilot scale GlidArc-I and-II reactors for gases, vapours, liquids, and solids processing (decomposition, conversion, upgrading, activation) as well as for flames overheating or stabilization (flaring for example). More than twenty French and foreign patents protect some of GlidArc-I and -II principles, powering, and applications.

2.3. GlidArc-III

Since long time we have been also working on plasma assisted partial oxidation of various fuels into the synthesis gas [6]. During this process it appeared that soot or other solid particles could deposit on high-voltage insulators of the GlidArc-I electrodes. Generally, only two electrodes are needed for such application to ignite and then to support such partial oxidation at less than 1% dissipated electric energy with respect to the enthalpy of the SynGas. New GlidArc-III plasma source [7] solves this problem.

As shown on Fig. 5 we direct 5-20% of the air *(1)* to a vortex-like zone *(2)* that protects one central GlidArc-III electrode *(3)* while the remaining part of the oxidant is sent through *(4)*, together with the processed fuel, to the plasma zone *(5)* where the gliding and rotating high-voltage AC discharge strikes between the central electrode *(3)* and the surrounding metallic nozzle *(6)* being at the ground potential The fuel and its pyrolysis products cannot now harm the dielectric support *(7)* of the central electrode. A Diesel fuel conversion into Synthesis Gas was successfully performed this year.
Figures 5 and 6 present our GlidArc-III reformer for various fuels processing.

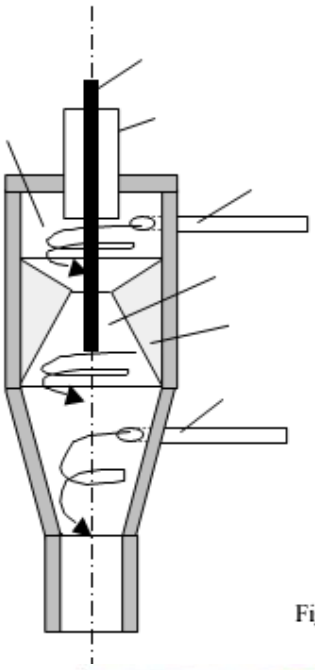

Fig. 4. Principle of the GlidArc-III.

Fig. 5. GlidArc-III discharge.

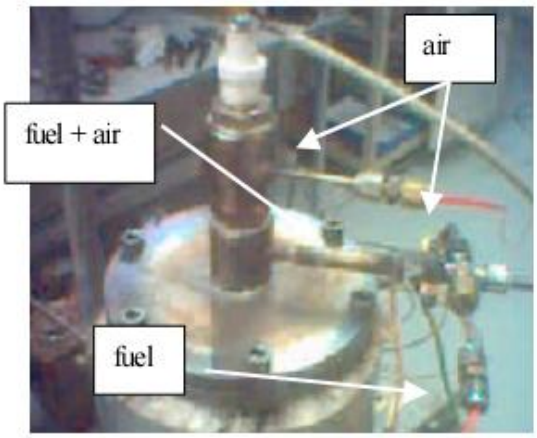

Fig. 6. GlidArc-III at the top of the Fuel Reformer body

3. Conclusion

A 45 years in-house story of construction and development of various plasma sources for various applications indicates that GlidArc-type generators are the best solution for plasma-chemical applications.

They can be as powerful as classical plasma torches while avoiding specific power supplying, water-cooling, electrode erosion, and quite complicated manufacturing. GlidArc instabilities rather help progressing the chemical processes by creating strong fluid turbulences (mixing) and generating very active catalytic species at quite low processed fluid temperature. We are proud to submit already three generations of these low-cost and low-tech devices to the Plasma Chemistry Community.

References

[1] H. Lesueur, A. Czernichowski, J. Chapelle, Dispositif de Génération de Plasmas Basse Température par Formation de Décharges Electriques Glissantes, French Patent No.2 639 172 (1988).
[2] A. Czernichowski, B. Hnatiuc, P. Pastva, A. Ranaivosoloarimanana, Générateurs et circuits électriques pour alimenter des décharges instables de haute tension, French Patent No. 2 817 444 (2000).
[3] A. Czernichowski, M. Czernichowski, Dispositif modulaire pour générer de multiples décharges électriques glissantes de haute tension, French Patent No. 2 842 389 (2002).
[4] J. Janca, S. Kuzmin, A. Maximov, J. Titova, A. Czernichowski, Investigation of the Chemical Action of the Gliding and "Point" Arcs Between the Metallic Electrode and Aqueous Solution, Plasma Chemistry and Plasma Processing, vol. 19(1) 53-67 (1999).
[5] A. Czernichowski, J. Sünnen, Procédé et dispositif de production d'un plasma hors d'équilibre, French Patent No. 2 763 778 (1997)
[6] A. Czernichowski, P. Czernichowski, Partial Oxidation of fossil and renewable fuels into the synthesis gas, this Symposium.
[7] A. Czernichowski, M. Czernichowski, K. Wesolowska, French application (2004).

Attachment "F"

(The following report, which pertains solely to emissions measurement testing, was commissioned by McMinnville Electric System as part of this Project and is therefore incorporated and made part of this Final Report as submitted.)

SECOR

SECOR INTERNATIONAL INCORPORATED
318 Seaboard Lane, Suite 101
Franklin, Tennessee 37067
615-794-12524TEL / 615-794-3076 FAX
www.secor.com

letter of transmittal

attention: Mr. Jeryl Stewart date: December 21, 2006

company: Tennessee Department of Environment and Conservation
Office of Air Pollution Control

address: 9th Floor L&C Annex
401 Church Street
Nashville, TN 37243-1531

project: McMinnville Electric System, McMinnville, TN

job no.: 17OT.98726.00

re: Emissions Measurements for McMinnville Electric System

enclosed:

( )	Proposal	( )	As Requested
( )	Contract	(X)	Review
(X)	Report	( )	Your Information
( )	Letter	( )	Approval
( )	Other:	( )	Signature
		( )	Return
		( )	Other:

comments:

Attached please find the Emissions Measurements Report for McMinnville Electric System in McMinnville, TN for your review.

signator: David S. West
title: Manager of Emissions Measurements

cc: Ms. Helen S. Hennon, P.E. (QEE)
Mr. Rodney Boyd (MES)

FINAL

EMISSIONS MEASUREMENTS REPORT FOR

MCMINNVILLE ELECTRIC SYSTEM

200 West Morford Street
McMinnville, Tennessee

December 2006
17OT.98726.00

Prepared by:

SECOR International Incorporated
318 Seaboard Lane, Suite 101
Franklin, Tennessee 37067

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EXECUTIVE SUMMARY

McMinnville Electric System (MES) operates an electric generating facility located in McMinnville, Tennessee. As detailed in Construction Permit No. 957279F, issued by the Tennessee Department of Environment and Conservation, Division of Air Pollution Control (APC), MES has installed a Caterpillar Model D3516B TA Diesel Engine and Caterpillar SR4B electric generating unit equipped with selective catalytic oxidation (SCO) for the control of the nitrogen oxides (NO_x) emissions. The unit is identified as emission source reference no. 89-0104-01 in the construction permit. As prescribed in Condition 15 of the construction permit, MES must conduct an emissions performance test to demonstrate compliance with the NO_x emission limit.

The performance test was conducted while the unit was firing a 99.9 percent biodiesel/0.1 percent ultra low sulfur diesel (ULSD) mixture. The SCO control device was not operational during this compliance program. The construction permit details the NO_x emissions factors at multiple biodiesel/ULSD fuel mixture ratios. Based on the data provided in the construction permit, the potential NO_x emissions increase as the percentage of biodiesel in the fuel mixture increases. This operating scenario provided a worst case condition for NO_x emissions from the unit.

MES retained SECOR International Incorporated (SECOR) to prepare the test plan and protocol (TPP) and complete the emissions measurement program. Mr. Gary Ewing, Senior Project Engineer, was the designated Project Manager for this test program. Mr. Ewing may be reached at SECOR's Tennessee office located at 318 Seaboard Lane, Suite 101, Franklin, Tennessee 37067, by telephone at (615) 794-1524, by fax at (615) 794-3076, or by email at gewing@secor.com. Mr. Rodney Boyd of MES was responsible for the coordination of the test program. Mr. Boyd may be reached by telephone at (931) 235-7007.

The emissions measurement program was performed November 28, 2006 in accordance with the TPP dated November 8, 2006 and applicable US EPA Reference Methods. No deviations were required. The results of the testing program demonstrate compliance with the limits specified in the permit. Table E.1 provides a summary of the results of the emissions measurements program.

E.1 SUMMARY OF EMISSIONS MEASUREMENTS RESULTS
MCMINNVILLE ELECTRIC SYSTEMS
NOVEMBER 28, 2006

	Generator Energy	Effluent Stream Conditions		NO_x Emissions		
Run No.	(kWh)	t_s (°F)	Q_s (dscfm)	ppm_{vd}	lb/hr	lb / $1x10^3$ kWh
1	1,654	633.3	5,581	740.88	29.64	17.920
2	1,654	632.8	5,615	744.59	29.97	18.120
3	1,653	639.0	5,551	746.11	29.69	17.961
Avg	**1,654**	**635.0**	**5,582**	**743.9**	**29.8**	**18.000**
Emission Limit[1]		--	--	--	--	**31.21**

[1] Unrestricted Fuel Mix / Uncontrolled

1.0 INTRODUCTION

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The emissions measurement program was performed November 28, 2006 in accordance with the TPP dated November 8, 2006 and applicable US EPA Reference Methods (RM). No deviations were required. The results of the testing program demonstrate compliance with the limits specified in the permit. SECOR personnel including Mr. David West and Mr. Briggs Evans performed the field measurements program. Mr. Bryan Parker of APC observed the field measurements program. Table 1.1 provides a summary of the methodologies followed for the compliance program.

Section 2.0 of this test report presents a detailed discussion of the results. The test methodologies employed, including instrument calibration, are presented in Section 3.0. A concise description of the quality assurance/quality control (QA/QC) procedures implemented is provided in Section 4.0.

TABLE 1.1 COMPLIANCE EMISSIONS MEASUREMENT PROGRAM
MCMINNVILLE ELECTRIC SYSTEM
NOVEMBER 28, 2006

Sample/ Measurement Location	No. of Runs	Analyte/ Parameter	Sampling/ Measurement Method	Sample Run Time	Analytical Method
Engine Exhaust	3	Volumetric Flow Rate	Methods 1 & 2	N/A	N/A
	3	O_2/CO_2	Method 3A	60 minutes	Method 3A Paramagnetic/Infrared
	3	Moisture	Method 4	60 minutes	Method 4 Gravimetric/Volumetric
	3	NO_x	Method 7E	60 minutes	Method 7E Chemiluminescent Analyzer

2.0 TEST PROGRAM SUMMARY

The following section provides a summary of the November 28, 2006 compliance emissions measurements program. The emissions measurements program was performed following the test methods and procedures detailed in *40 CFR 60, Appendix A*. The determination of the effluent stream's diluent concentrations was accomplished following *40 CFR 60, Appendix A, Reference Method (RM) 3A, "Determination of Oxygen and Carbon Dioxide Concentrations in Emissions from Stationary Sources (Instrumental Analyzer Procedure)."* The oxygen (O_2) concentration was determined using a paramagnetic analyzer and the carbon dioxide (CO_2) concentration was determined using an infrared (IR) analyzer. The determination of the NO_x emissions was accomplished following the procedures of RM 7E, *"Determination of Nitrogen Oxide Emissions from Stationary Sources (Instrumental Analyzer Procedure)."* The NO_x concentration was determined using a chemiluminescent analyzer.

Concurrent with each sample run, RMs 1, 2, and 4 were performed at the sample location in order to determine the volumetric flow rate and moisture content of the effluent stream. Upon completion of the sampling program, the NO_x and CO data measured by the RM 7E sample system was combined with the measured effluent stream's volumetric flow rate in order to determine the mass emission rate, expressed as pounds per hour (lb/hr). A total of three 60-minute runs were completed for each compliance program.

The field measurements were conducted under normal process operations. SECOR and MES staff maintained close communication to ensure that the collected samples were representative and typical of the process emissions at the time of testing.

The emissions testing program was performed as prescribed in RM 7E. The average measured NO_x concentration was 743.9 parts per million, by volume, dry basis (ppm_{vd}). This equates to an average NO_x mass emission rate of 29.8 lb/hr at the average measured volumetric flow rate of 5,582 dry standard cubic feet per minute (dscfm). The engine operated at an average of 1,654 kilowatts per hour (kWh) during the test program. This equates to a NO_x mass emission rate of 18.67 lb/1,000 kWh.

The results of the test program demonstrate compliance with the permitted NOx emission limit of 31.21 lb/1,000 kWh for an uncontrolled, unrestricted fuel mix. Table 2.1 provides the results of the emissions measurements program. The supporting data for this sample program is included in the appendices.

TABLE 2.1 NO_X EMISSIONS MEASUREMENT RESULTS
MCMINNVILLE ELECTRIC SYSTEM
NOVEMBER 28, 2006

	Run 1	Run 2	Run 3	Average
Sample Period	10:27-11:27	12:00-13:00	13:24-14:24	--
Generator Energy, kWh	1,654	1,654	1,653	**1,654**
Sample Time, min	60	60	60	--
Barometric Pressure, P_{bar} (in. Hg)	29.10	29.10	29.05	**29.08**
Dry Gas Meter I.D.	1	1	1	--
Meter Corr. Factor, Y	0.955	0.955	0.955	--
Meter $\Delta H_@$	1.994	1.994	1.994	--
Pitot Coefficient, C_p	0.84	0.84	0.84	--
Duct Diameter, in.	15.75	15.75	15.75	--
Duct Area (A_s), ft^2	1.35	1.35	1.35	--
Effluent Stream Conditions				
Temperature, °F	633.3	632.8	639.0	**635.0**
O_2 Concentration, %	11.3	11.3	11.3	**11.3**
CO_2 Concentration, %	7.2	7.2	7.2	**7.2**
Static Pressure, P_g	1.90	2.20	2.70	**2.27**
Stack Pressure, P_s	29.24	29.26	29.25	**29.25**
Effluent Steam Moisture Calculations				
Meter Volume, ft^3	34.185	30.665	34.100	**32.983**
Avg. Dry Gas Meter Temp. (°F)	77.5	84.4	84.4	**82.1**
H_20 Gain, V_{lc}	59.3	59.4	56.2	**58.3**
Avg. ΔH	1.0	1.0	1.0	**1.0**
Meter Pressure, in. Hg	29.17	29.17	29.12	**29.16**
Standard Meter Volume, ft^3 (Vm_{std})	31.300	27.720	30.773	**29.931**
Standard Water Volume, ft^3 (Vw_{std})	2.791	2.796	2.645	**2.744**
Moisture Fraction, Saturation	1.0000	1.0000	1.0000	**1.0000**
Moisture Fraction, Measured	0.0819	0.0916	0.0792	**0.0842**
Applicable Moisture (lower Sat. vs. Meas.)	0.0819	0.0916	0.0792	**0.0842**
Volumetric Flow Rate				
Avg. SQRT ΔP	1.9342	1.9615	1.9238	**1.9398**
Mol. Wt. Stack Gas, (M_d)	29.60	29.60	29.60	**29.60**
Mol. Wt. Stack Gas, (M_s)	28.65	28.54	28.68	**28.62**
Velocity, (V_s)	158.67	161.13	158.12	**159.30**
At Stack Conditions, acfm (Q_a)	12,880	13,080	12,836	**12,932**
At Wet Standard Conditions, wscfm (Q_{sw})	6,081	6,183	6,030	**6,098**
At Standard Conditions, dscfm (Q_s)	5,581	5,615	5,551	**5,582**
NO_x Emissions Data				
ppm_{vd}	740.88	744.59	746.11	**743.9**
lb/hr	29.64	29.97	29.69	**29.8**
lb/1,000 kWh	17.920	18.120	17.961	**18.000**
Permit Limit, lb/1,000 kWh[1]	--	--	--	**31.21**

[1] Unrestricted fuel mix, uncontrolled.

3.0 TEST METHODOLOGY

The testing program was performed according to the following accepted and approved EPA RMs as contained in the EPA's *Quality Assurance Handbook for Air Pollution Measurement Systems, Volume III, Stationary Source Specific Methods, in 40 CFR 60, Appendix A.* The general procedures followed to complete this measurement evaluation include:

RM 1	Sample and Velocity Traverses for Stationary Sources
RM 2	Determination of Stack Gas Velocity and Volumetric Flow Rate (Type-S Pitot Tube)
RM 3A	Determination of Oxygen and Carbon Dioxide Concentrations in Emissions from Stationary Sources (Instrumental Analyzer Procedure)
RM 4	Determination of Moisture Content in Stack Gases
RM 7E	Determination of Nitrogen Oxides Emissions from Stationary Sources (Instrumental Analyzer Procedure)

3.1 Support Measurements for Stack Parameters

EPA Reference Methods 1 through 4 were performed to provide support data for emission rate calculations. Ideally, measurements should be performed at least eight stack diameters downstream and two diameters upstream from any flow disturbance. RM 1, *"Sample and Velocity Traverses for Stationary Sources,"* was conducted using existing test port locations prior to the initiation of the measurements.

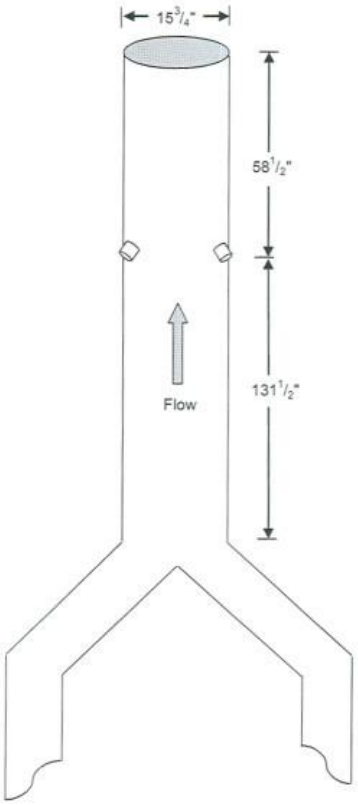
3.1.1 Selection of Traverse Points

EPA RM 1, "*Sample and Velocity Traverses for Stationary Sources,*" was followed for the selection of measurement points at the test location. The sample location was measured in order to determine the stack diameter and the distance to the nearest upstream and downstream disturbances. This data was used to determine the minimum number of traverse points as detailed in Figure 1-1 of RM 1. For circular stacks, the traverse points were located on two perpendicular diameters according to Table 1-2 of RM 1. Figure 3.1 provides an illustration of the sample location.

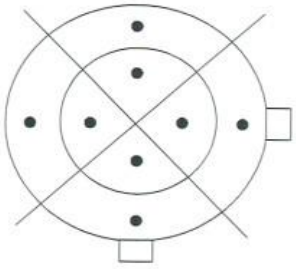
3.1.2 Flow Rate Determination

The volumetric flow rate at the stack test location was measured using EPA RM 2, "*Determination of Stack Gas Velocity and Volumetric Flow Rate (Type-S Pitot Tube).*" A stainless steel, Type-S Pitot tube connected to a differential pressure gauge (inclined manometer) was used to measure the pressure differential at each traverse point. The measured velocity head, observed at each traverse point, was recorded on a field data sheet and used for determining the overall volumetric flow rate.

FIGURE 3.1 SAMPLE LOCATION ILLUSTRATION FOR ENGINE EXHAUST
MCMINNVILLE ELECTRIC SYSTEM
NOVEMBER 28, 2006



Traverse Point	Distance from Wall	Distance with Port
1	1.1	2.4
2	3.9	5.2
3	11.8	13.1
4	14.6	15.9



In addition to the velocity head, gas temperatures were measured and recorded concurrently with all the velocity head data. The temperature was measured with a Type-K thermocouple attached to a digital temperature indicator. Temperature readings were recorded from the display of the calibrated digital temperature indicator. The velocity head and temperature data were recorded on field data forms.

The average stack gas velocity was calculated using the gas density, the average measured velocity head (differential pressure), and the average measured gas temperature. The flow rate results are presented in terms of acfm (actual cubic feet per minute) and dscfm (dry standard cubic feet per minute).

3.1.3 Moisture Content Determination

The effluent moisture content at the test location was determined using EPA RM 4, "*Determination of Moisture Content in Stack Gases.*" The determination of moisture content was accomplished using a condenser and pump assembly connected between a sample probe and metering system.

Throughout each sample run, a known volume of gas (measured by a dry gas meter) passed through the condenser assembly. Upon completion of each sample run, the total amount of condensate collected was volumetrically/gravimetrically measured and the net gain calculated. The total moisture gain, volume of gas extracted, and measured meter temperature data were used to calculate the actual moisture content of the effluent. Figure 3.2 provides a schematic of the RM 4 sample system.

3.2 CEMS Sampling System Description

The continuous emissions measurements system (CEMS) consists of an in-stack filter assembly, sample probe, sample gas conditioner, Teflon® sample line, sample pumps and analyzers. A sample of the effluent gas is continuously drawn from the sample location through the in-stack filter assembly, stainless steel probe, gas conditioning system and Teflon® sample line via a Teflon® coated sample pump. The sample gas is then passed through the sample gas manifold prior to delivery to the instrumental analyzers.

The following specific support equipment, instrumentation, and data acquisition systems are incorporated into the gaseous monitoring system to provide reliable and defensible data.

- In-stack Filter Assembly: The in-stack filter assembly is composed of a stainless steel filter holder and 0.1 micron filter.
- Sample Probe: Stainless steel probe inserted through the sample port.
- Moisture Removal System: A stainless steel condenser assembly is used for the sample gas conditioning system. The sample gas conditioning system is located downstream of the sample probe. The gas conditioning system continuously removes condensate from the sample gas without changing the dry concentration of the sample gas. This

approach is completed with minimal contact between the condensate and the sample gas.

- Sample Line: Teflon® tubing is used to transport the sample gas from the gas conditioning system to the sample pump and gas manifold.

- Data Acquisition: A digital data logger is used for data capture. The electronic output (response) of the analyzers to the calibration standards and the sample gas is continuously directed to the digital data logger and recorded at one-minute intervals. A Campbell Scientific Model 21X data logger is used as the primary data acquisition system. The data collected by the data logger (one-minute averages) is used for all data reduction and compliance determinations. Additionally, a digital strip chart recorder is used as a secondary data acquisition system. The data from the digital strip chart recorder is maintained electronically in the appropriate project directory. The digital strip chart recorder data is only utilized if the data from the primary data acquisition system is corrupt.

3.2.1 Measurement System Performance

The CEM system is composed of several different analyzers. Diluent O_2 and CO_2 are quantified, on a percent, dry basis, using a California Analytical Instruments Model 300, or equivalent, Paramagnetic O_2 analyzer and non-dispersive infrared (NDIR) CO_2 analyzer. A Thermal Environmental Incorporated (TEI) Model 42H, or equivalent, chemiluminescent NO_x analyzer is used to measure the effluent NO_x concentration. The NO_x concentration data is measured on a parts per million, by volume, dry basis (ppm_{vd}).

All calibration gases are documented traceable to National Bureau of Standards Reference Materials according to the *"EPA Traceability Protocol for Assay and Certification of Gaseous Calibration Standards,"* September 1997, as amended August 25, 1999, EPA-600/R-97/121. Certification from the gas manufacturer(s) that the protocol was followed is provided in the report appendices.

3.2.2 O_2, CO_2, and NO_x Measurements

The determinations of the O_2, CO_2, and NO_x concentrations of the effluent stream will be accomplished following the sampling methodologies detailed in EPA's *Code of Federal Regulations, Title 40, Part 60 (40 CFR 60), Appendix A.* Specifically, the O_2 and CO_2 determinations are accomplished following RM 3A, *"Determination of Oxygen and Carbon Dioxide Concentrations in Emissions from Stationary Sources (Instrumental Analyzer Procedure)"* and the NO_x following RM 7E, *"Determination of Nitrogen Oxide Emissions from Stationary Sources (Instrumental Analyzer Procedure)."*

3.2.2.1 Calibration Gas Checks

Each of the previously mentioned Reference Methods requires the following calibration gas mixtures for calibration:

- High-Level Gas: Calibration gas with a concentration that is equal to the calibration span.
- Mid-Level Gas: Calibration gas with a concentration that is 40 to 60 percent of the calibration span.
- Low-Level Gas: Calibration gas with a concentration less than 20 percent of the calibration span and may be a zero gas.

To calibrate each instrument, the gas standards are introduced directly to each monitor at the sample inlet located on the back of the instrument. The response of each analyzer compared to each certified calibration standard must be within ±2 percent of the analyzer span value for each component as required in each method.

3.2.2.2 Calibration Drift and Measurement System Bias Checks

The amount of bias of the sample system is also determined. This is accomplished by introducing the low-level and one (1) up-scale (high-level or mid-level) calibration gas to the CEMS at the point at which the sample probe and sample line are connected. The calibration gas which best approximates the emissions is selected as the up-scale gas. The response of each analyzer to the direct zero and span gases (bias check) must be less than ±5 percent of the span value for each component as required by the methods. The bias calibration check is performed prior to and upon completion of each sample run.

The magnitude of calibration drift is also calculated. Calibration drift is the difference in the initial (pre-test) bias calibration response and the final (post-test) bias calibration response for the same gas standard. The calibration drift must be within ±3 percent of the span over each sample run for each component gas standard as required by the method.

3.2.2.3 Interference Response

Interference response is based on instrument vendor data, which demonstrates that the interference performance specification is not exceeded. Information will be provided upon request.

3.2.2.4 Sample System Response Time

To determine response time for each component, up-scale gas is introduced into the probe upstream of all sample conditioning components. The time required for the measured concentration to increase to a value that is within 95 percent or 0.5 ppm (whichever is less restrictive) of the certified gas concentration is recorded. This is the up-scale system response time. The low-level gas is then introduced to the system and the time for the concentration response to decrease to a value that is within 5.0 percent or 0.5 ppm (whichever is less

restrictive) of the certified low-range gas concentration is recorded. This is the downscale system response time. The response test is conducted prior to the commencement of the performance test and only repeated if changes are made in the measurement system.

3.2.2.5 NO_2 to NO Conversion Efficiency

The NO_x analyzer used during the testing program will undergo the conversion efficiency test detailed in 40 CFR 60, Appendix A, RM 7E, Section 8.2.4. The converter efficiency test is conducted prior to mobilization to the project site. The NO_2 to NO conversion efficiency must be found to meet or exceed the minimum criteria specified in RM 7E (≥ 90 percent of the certified test gas concentration.

3.2.2.6 Stratification Test

Prior to conducting the compliance test program, the stratification test is conducted as prescribed in Section 8.1 of RM 7E. The stratification test must be performed at twelve traverse points located according to Table 1-1 or Table 1-2 of RM 1. Alternatively, measurements may be conducted at three points on a line passing through the centroidal area. The three points must be spaced at 16.7, 50.0, and 83.3 percent of the measurement line. Sampling is conducted at a minimum of twice the system response time at each traverse point. The individual point and mean NOx concentrations are then calculated. The individual point data is compared with the mean concentration in order to determine the minimum number of traverse points to be used for the compliance program as prescribed in Section 8.1.2 of RM 7E.

FIGURE 3.2 RM 4 SAMPLING SYSTEM SCHEMATIC
MCMINNVILLE ELECTRIC SYSTEM
NOVEMBER 28, 2006

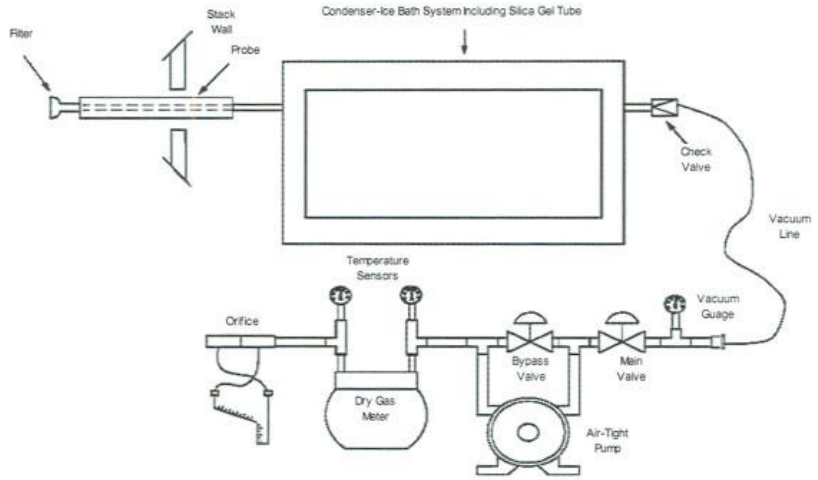
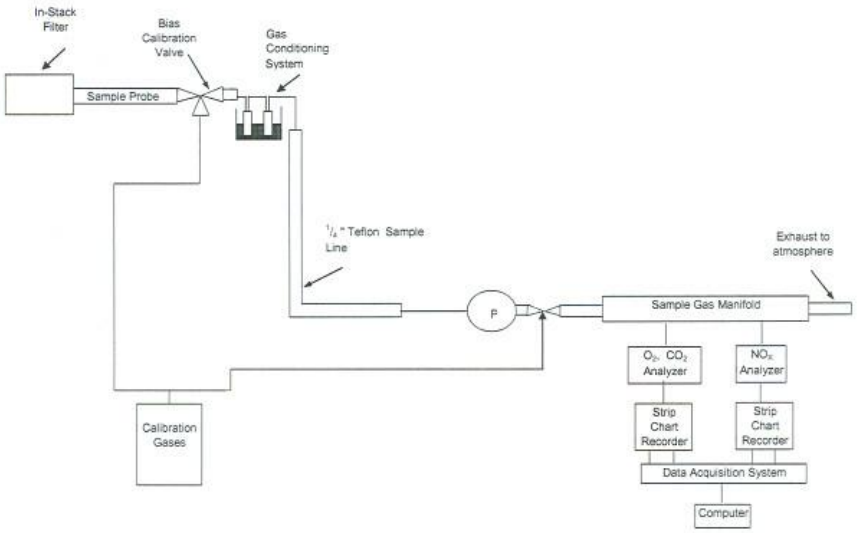


FIGURE 3.3 CEM SYSTEM ILLUSTRATION
MCMINNVILLE ELECTRIC SYSTEM
NOVEMBER 28, 2006



3.3 Calculations and Nomenclature

The following section presents the calculations for determining moisture content, dry sample gas volume, and mass flow rate. In addition, calculations for the determination of NO_x concentrations are provided. The nomenclature for each calculation is also defined.

3.3.1 Calculations

Stack Pressure (in. Hg):

$$P_s = P_{bar} + \frac{P_g}{13.6}$$

Meter Pressure (in. Hg):

$$P_m = P_{bar} + \frac{\Delta H}{13.6}$$

Dry Standard Sample Gas Volume ($dsft^3$):

$$V_{m(std)} = V_m \, x \, Y_d \, x \left(\frac{T_{std}}{T_m}\right) x \left(\frac{P_m}{P_{std}}\right)$$

Volume of Water Vapor (scf):

$$V_{w(std)} = 0.04707 \, x \, V_{lc}$$

Proportional Moisture Content:

$$B_{ws} = \frac{V_{w(std)}}{V_{w(std)} + V_{m(std)}}$$

Percent Moisture (%):

$$\%\, H_2O = B_{ws} \, x \, 100$$

Molecular Weight (dry):

$$M_d = (0.44 \, x \, \%\, CO_2) + (0.32 \, x \, \%\, O_2) + (0.28 \, x \, (100 - \%\, CO_2 - \%\, O_2))$$

Molecular Weight (wet):

$$M_s = M_d \, x \, (1 - B_{ws}) + (18.0 \, x \, B_{ws})$$

Velocity (fps):

$$v_s = 85.49 \times C_p \times \sqrt{\Delta p}_{avg} \times \sqrt{\frac{T_s}{P_s \times M_s}}$$

Flow Rate (acfm):

$$Q_a = v_s \times A_s \times 60$$

Flow Rate (wscfm):

$$Q_{sw} = Q_a \times \left(\frac{T_{std}}{T_s}\right) \times \left(\frac{P_s}{P_{std}}\right)$$

Flow Rate (dscfm):

$$Q_s = Q_{sw} \times (1 - B_{ws})$$

Pollutant Mass Emission Rate (lb/hr):

$$MER = ppm_{vd} \times \frac{MW}{385.1 \times 10^6} \times Q_s \times 60$$

3.3.2 Nomenclature

P_s	absolute pressure of stack gas (in. Hg)
P_{bar}	uncorrected barometric pressure (in. Hg)
P_g	static pressure of stack gas (in. H_2O)
P_m	absolute dry gas meter pressure (in. Hg)
ΔH	average pressure differential across the orifice meter (in. H_20)
$V_{m(std)}$	dry gas volume corrected to standard conditions ($dsft^3$)
V_m	dry gas volume as measured by the DGM (aft^3)
Y_d	DGM calibration factor
T_{std}	standard absolute temperature (528 °R)
T_m	average DGM absolute temperature (°R)
P_{std}	standard absolute pressure (29.92 in. Hg)
$V_{w(std)}$	volume of water vapor collected corrected to standard conditions (sft^3)
V_{lc}	volume of water vapor collected
B_{ws}	water vapor in gas stream (proportional by volume)
$\%H_2O$	percent moisture content of gas
M_d	molecular weight of stack gas, dry basis (lb/lb-mole)
$\%CO_2$	percent carbon dioxide, dry basis
$\%O_2$	percent oxygen, dry basis

M_s	molecular weight of stack gas, wet basis (lb/lb-mole)
v_s	average gas velocity (feet per second)
C_p	pitot tube coefficient, dimensionless (0.84 for Type-S)
Δp	velocity head of gas (in. H_2O)
T_s	stack gas temperature (°R)
Q_a	volumetric flow rate (actual cubic feet per minute)
A_s	cross sectional area of the stack (square feet)
Q_{sw}	volumetric flow rate (wet standard cubic feet per minute)
Q_s	volumetric flow rate (dry standard cubic feet per minute)
MER	mass emission rate (lb/hr)
ppm_{vd}	part per million, by volume, dry basis
MW	pollutant molecular weight (lb/lb-mole), (NO_x = 46.01)

3.3.3 Constants and Conversions

13.6	specific gravity of mercury (in. H_2O/in. Hg)
0.04707	water vapor conversion factor (ft^3/mL)
100	conversion to percent
0.44	molecular weight of carbon dioxide, divided by 100 (lb/lb-mole)
0.32	molecular weight of oxygen, divided by 100 (lb/lb-mole)
0.28	molecular weight of nitrogen or carbon monoxide, divided by 100 (lb/lb-mole)
18.0	molecular weight of water (lb/lb-mole)
	$\left(\frac{ft}{\sec}\right)\sqrt{\left[\frac{\left(\frac{lb}{lb\text{-}mole}\right)(in.\ Hg)}{(°R)(in.\ H_2O)}\right]}$
85.49	pitot tube constant,
60	conversion factor for seconds per minute (sec/min) (acfm)
60	conversion factor for minutes per hour (min/hr) (mass emission rate)
385.1×10^6	mass to volume conversion factor at standard conditions ($dsft^3$/lb-mole)

3.3.4 Example Calculations, Engine Exhaust, Run 1

Note that the values presented here are rounded numbers and results are those from the spreadsheet calculations. Results calculated using the rounded values may vary slightly.

Stack Pressure (in. Hg):

$$29.24 = 29.10 + \frac{1.90}{13.6}$$

Meter Pressure (in. Hg):

$$29.17 = 29.10 + \frac{1.0}{13.6}$$

Dry Standard Sample Gas Volume ($dsft^3$):

$$31.300 = 34.185 \times 0.955 \times \left(\frac{528}{537.5}\right) \times \left(\frac{29.17}{29.92}\right)$$

Volume of Water Vapor (scf):

$$2.791 = 0.04707 \times 59.3$$

Proportional Moisture Content:

$$0.0819 = \frac{2.791}{2.791 + 31.300}$$

Percent Moisture (%):

$$8.19 = 0.0819 \times 100$$

Molecular Weight (dry):

$$29.60 = (0.44 \times 7.2) + (0.32 \times 11.3) + (0.28 \times (100 - 7.2 - 11.3))$$

Molecular Weight (wet):

$$28.65 = 29.60 \times (1 - 0.0819) + (18.0 \times 0.0819)$$

Velocity (fps):

$$158.637 = 85.49 \times 0.84 \times 1.9342 \times \sqrt{\frac{1{,}093.3}{29.24 \times 28.65}}$$

Flow Rate (acfm):

$$12{,}880 = 158.67 \times 1.35 \times 60$$

Flow Rate (wscfm):

$$6{,}081 = 12{,}880 \times \left(\frac{528}{1{,}093.3}\right) \times \left(\frac{29.24}{29.92}\right)$$

Flow Rate (dscfm):

$$5{,}581 = 6{,}081 \times (1 - 0.0819)$$

Pollutant Mass Emission Rate (lb/hr):

$$29.64 = 740.88 \times \frac{46.01}{385.1 \times 10^{6}} \times 5{,}581 \times 60$$

4.0 QUALITY ASSURANCE / QUALITY CONTROL

The overall objective of SECOR's Quality Assurance/Quality Control (QA/QC) program is to ensure the collection of valid and acceptable data from all environmental measurement projects. Acceptable data is defined in terms of accuracy, precision, completeness, and representativeness.

Quality Control activities are carried out during routine project operations to ensure that the data produced are within established limits of accuracy and precision. Quality Assurance activities are carried out externally and independent of routine project endeavors to document data quality.

Each air measurement program entails numerous activities, during which critical QA/QC measures must be incorporated to achieve overall project data quality objectives. Specific QA measures are implemented during each of the following phases of field and laboratory operations:

- Presampling activities
- Sample collection
- Data reduction and reporting

General QA/QC measures and objectives incorporated into all source measurement programs include the following:

- Continually monitor the precision and accuracy of the data being generated for all environmental measurements.
- Implement measures designed to control the precision and accuracy of all data generated for individual sources.
- Maintain permanent records of equipment calibrations that include traceability and certification.

4.1 Presampling Activities and QA Measures

Presampling activities include equipment maintenance and calibration. All monitoring equipment is uniquely identified and subjected to continuous preventive maintenance measures at SECOR's Franklin, Tennessee office location. Records of instrument maintenance and calibration are maintained and continually updated. All instrumental analyzers and applicable sampling system components are calibrated prior to and after all field measurements programs according to stringent guidelines set forth in the *Quality Assurance Handbook for Air Pollution Measurement Systems, Volume III, Stationary Source Specific Methods and the 40 CFR 60, Appendix A* and *F*.

4.2 Field Program

The EPA or applicable local agency, prior to sample initiation, approved field sampling and measurements procedures used in all source measurements programs. All primary emissions testing procedures are referenced in the *EPA 40 CFR 60, Appendix A* and the *EPA Quality Assurance Handbook for Air Pollution Measurement Systems, Volume III, Stationary Source Specific Methods*.

All field test personnel involved with this test program are experienced and trained in field sampling methods and procedures. Each field person is assigned key responsibilities in phases of sample collection, sample recovery, chain of custody, and transportation of samples. Basic responsibilities for field personnel include, but are not limited to:

- Record Keeping – Field personnel record all pertinent parameters and relevant observations on the appropriate field data forms.
- Safety Requirements – Field personnel are familiar with company safety regulations and are provided with necessary safety equipment.
- Sample Handling – Field personnel are trained in the proper procedures for handling samples including: use of sample containers, sample preservation, identification, storage of collected samples, and chain-of-custody.
- Instrumentation – Specific field personnel are trained in the proper operation, calibration, trouble shooting, and maintenance of the instrumentation intended for this program. This includes the use of pumps, control console(s), samplers, and instrumentation.
- Quality Control – Field personnel are trained in all aspects of quality control that relate directly to the specific reference method test procedures, sample handling, analysis, and reporting.

A member of the SECOR field team, Mr. David West, was designated as Field Manager and was responsible for coordinating testing activities with the client and answering questions concerning test methodology and quality control. The Field Manager was also responsible for delegating work assignments to the members of the test crew, making sure all QA/QC procedures were carried out, and documenting all field activities in a bound log book.

4.3 Sample Documentation

All field data collected for each selected reference method test procedure are documented on field data forms specifically designed for each particular method using recommended formats as described in *40 CFR 60, Appendix A* and the *EPA Quality Assurance Handbook for Air Pollution Measurement Systems, Volume III, Stationary Source Specific Methods*. Each form, specific to each particular sample run, includes information as to the source tested, date and time of sample collection, analyst(s) performing the test and all data necessary for test validation. Each field data sheet is completed by the responsible technician at the time of the test and checked by the Field Manager for accuracy and completeness after each test series. Copies of all raw

field data sheets are included in this emission test report with the originals maintained in project files at SECOR's Tennessee office.

4.4 Data Reduction and Reporting

SECOR has implemented specific measures to ensure that reliable data is generated as a result of the sampling and analytical activities of every field program. The objective of this phase of SECOR's QA/QC program is to follow the proper collection of representative and quality assured field and analytical data with approved data reduction methods and equations.

All calculations are performed using quality assured spreadsheets incorporating standard accepted equations, as required by the applicable pollutant specific sampling methodology. Data reduction is performed by qualified engineers or data analysts familiar with standard engineering practices and approved methods.

APPENDIX A
FIELD DATA AND SPREADSHEET CALCULATIONS

Emissions Measurements Report
McMinnville Electric System
200 West Morford Street
McMinnville, Tennessee
17OT.98726.00
December 2006

Run 2
CONTINUOUS EMISSION MEASUREMENT RESULTS
Engine Exhaust
November 28, 2006

Time	O_2 (%)	O_2 (% - Bias Corr.)	CO_2 (%)	CO_2 (% - Bias Corr.)	NO_x (ppm_{vd})	NO_x (ppm_{vd} - Bias Corr.)	NO_x (lb/hr)
1200	11.28	11.34	7.19	7.17	738.8	749.6	30.17
1201	11.24	11.29	7.19	7.17	740.6	751.5	30.25
1202	11.26	11.31	7.20	7.18	741.0	751.9	30.27
1203	11.24	11.29	7.20	7.18	740.7	751.6	30.25
1204	11.24	11.30	7.20	7.18	740.6	751.5	30.25
1205	11.25	11.30	7.19	7.17	742.9	753.8	30.34
1206	11.25	11.31	7.20	7.18	744.5	755.5	30.41
1207	11.26	11.31	7.19	7.17	744.9	755.9	30.43
1208	11.27	11.33	7.19	7.17	743.2	754.2	30.36
1209	11.25	11.31	7.19	7.17	743.0	754.0	30.35
1210	11.28	11.33	7.19	7.17	743.7	754.7	30.38
1211	11.26	11.32	7.19	7.17	741.3	752.3	30.28
1212	11.26	11.31	7.19	7.17	741.9	752.8	30.30
1213	11.26	11.32	7.19	7.17	741.0	751.9	30.26
1214	11.25	11.31	7.19	7.17	739.9	750.8	30.22
1215	11.26	11.31	7.18	7.16	740.5	751.4	30.25
1216	11.28	11.34	7.19	7.17	739.5	750.4	30.20
1217	11.25	11.30	7.19	7.17	738.7	749.5	30.17
1218	11.26	11.31	7.20	7.17	738.0	748.9	30.14
1219	11.25	11.31	7.20	7.18	737.4	748.2	30.12
1220	11.26	11.32	7.19	7.17	736.7	747.5	30.09
1221	11.27	11.32	7.19	7.16	736.8	747.6	30.09
1222	11.26	11.32	7.19	7.17	734.8	745.5	30.01
1223	11.27	11.32	7.19	7.17	733.6	744.4	29.96
1224	11.29	11.35	7.19	7.16	734.7	745.5	30.01
1225	11.28	11.33	7.18	7.16	734.3	745.1	29.99
1226	11.26	11.31	7.18	7.16	733.5	744.3	29.96
1227	11.27	11.32	7.19	7.17	732.0	742.7	29.90
1228	11.27	11.32	7.19	7.17	731.0	741.7	29.86
1229	11.26	11.32	7.18	7.16	730.2	740.9	29.82
1230	11.28	11.33	7.18	7.16	731.8	742.5	29.89
1231	11.28	11.33	7.18	7.16	731.1	741.9	29.86
1232	11.27	11.33	7.18	7.16	730.2	740.9	29.82
1233	11.27	11.32	7.19	7.17	728.9	739.6	29.77
1234	11.26	11.31	7.19	7.17	728.0	738.7	29.73
1235	11.27	11.32	7.19	7.16	728.7	739.3	29.76
1236	11.26	11.31	7.19	7.17	729.7	740.4	29.80
1237	11.26	11.31	7.19	7.17	729.9	740.6	29.81
1238	11.26	11.31	7.20	7.17	728.6	739.3	29.76
1239	11.27	11.32	7.19	7.17	728.7	739.4	29.76
1240	11.27	11.32	7.19	7.16	728.8	739.5	29.76
1241	11.27	11.33	7.19	7.17	728.4	739.0	29.75
1242	11.26	11.31	7.19	7.17	727.9	738.6	29.73
1243	11.26	11.31	7.20	7.17	728.1	738.8	29.74
1244	11.26	11.33	7.20	7.18	727.3	738.0	29.70
1245	11.27	11.32	7.20	7.18	727.9	738.6	29.73
1246	11.27	11.32	7.20	7.18	728.0	738.7	29.73
1247	11.27	11.33	7.20	7.18	727.2	737.9	29.70
1248	11.27	11.32	7.20	7.17	727.8	738.4	29.72
1249	11.28	11.33	7.20	7.18	728.3	739.0	29.75
1250	11.27	11.32	7.21	7.18	728.9	739.6	29.77
1251	11.25	11.30	7.21	7.19	728.3	739.0	29.74
1252	11.27	11.33	7.21	7.19	728.8	739.5	29.76
1253	11.26	11.31	7.21	7.18	729.6	740.3	29.80
1254	11.26	11.32	7.21	7.19	730.1	740.8	29.82
1255	11.25	11.30	7.22	7.19	729.0	739.6	29.77
1256	11.26	11.31	7.22	7.19	729.4	740.1	29.79
1257	11.26	11.31	7.22	7.19	730.7	741.4	29.84
1258	11.26	11.31	7.22	7.19	729.8	740.4	29.80
1259	11.25	11.31	7.23	7.20	729.5	740.2	29.79
Average	11.26	11.32	7.20	7.17	733.81	744.59	29.97

NOx_CEM_Data.xls run2

Run 3
CONTINUOUS EMISSION MEASUREMENT RESULTS
Engine Exhaust
November 28, 2006

Time	O_2 (%)	O_2 (% - Bias Corr.)	CO_2 (%)	CO_2 (% - Bias Corr.)	NO_x (ppm_{vd})	NO_x (ppm_{vd} - Bias Corr.)	NO_x (lb/hr)
1324	11.24	11.28	7.24	7.17	737.1	746.8	29.72
1325	11.25	11.30	7.25	7.17	738.1	747.8	29.76
1326	11.22	11.27	7.25	7.17	739.2	748.9	29.80
1327	11.24	11.29	7.24	7.17	739.1	748.8	29.80
1328	11.23	11.28	7.25	7.17	740.2	749.9	29.84
1329	11.24	11.29	7.25	7.17	740.5	750.2	29.85
1330	11.25	11.29	7.24	7.16	741.2	751.0	29.88
1331	11.24	11.29	7.24	7.16	741.5	751.2	29.89
1332	11.24	11.28	7.24	7.16	741.6	751.3	29.90
1333	11.23	11.28	7.25	7.17	740.9	750.7	29.87
1334	11.25	11.30	7.25	7.17	740.6	750.4	29.86
1335	11.23	11.28	7.25	7.17	740.7	750.4	29.86
1336	11.24	11.28	7.25	7.17	740.5	750.2	29.85
1337	11.24	11.28	7.25	7.17	740.6	750.3	29.86
1338	11.23	11.28	7.25	7.17	739.4	749.1	29.81
1339	11.23	11.28	7.25	7.18	740.3	750.0	29.84
1340	11.26	11.30	7.26	7.18	741.0	750.8	29.88
1341	11.23	11.28	7.26	7.18	740.3	750.0	29.84
1342	11.24	11.29	7.26	7.18	740.0	749.7	29.83
1343	11.24	11.28	7.26	7.18	740.0	749.7	29.83
1344	11.23	11.28	7.27	7.20	739.1	748.8	29.80
1345	11.24	11.29	7.26	7.19	738.9	748.6	29.79
1346	11.24	11.29	7.26	7.18	738.8	748.5	29.78
1347	11.24	11.29	7.26	7.19	737.3	747.0	29.72
1348	11.24	11.29	7.26	7.19	737.0	746.6	29.71
1349	11.23	11.28	7.27	7.19	737.3	747.0	29.72
1350	11.24	11.29	7.27	7.20	737.6	747.3	29.74
1351	11.24	11.28	7.27	7.20	738.2	747.9	29.76
1352	11.23	11.28	7.27	7.20	738.2	747.9	29.76
1353	11.24	11.29	7.27	7.20	737.9	747.6	29.75
1354	11.23	11.28	7.28	7.20	739.4	749.1	29.81
1355	11.23	11.28	7.29	7.21	738.6	748.3	29.78
1356	11.22	11.27	7.29	7.21	737.7	747.4	29.74
1357	11.24	11.29	7.28	7.21	738.1	747.8	29.76
1358	11.24	11.29	7.28	7.21	738.5	748.2	29.77
1359	11.24	11.29	7.28	7.21	737.6	747.2	29.73
1400	11.24	11.29	7.29	7.21	737.9	747.6	29.75
1401	11.23	11.28	7.29	7.21	736.8	746.4	29.70
1402	11.25	11.30	7.29	7.21	737.9	747.6	29.75
1403	11.22	11.27	7.29	7.21	738.0	747.7	29.75
1404	11.24	11.29	7.29	7.21	737.1	746.8	29.72
1405	11.25	11.29	7.28	7.21	738.1	747.8	29.76
1406	11.25	11.30	7.29	7.21	738.2	747.9	29.76
1407	11.25	11.30	7.29	7.21	736.7	746.3	29.70
1408	11.25	11.30	7.29	7.21	736.2	745.8	29.68
1409	11.25	11.30	7.29	7.21	736.3	746.0	29.68
1410	11.26	11.30	7.29	7.21	735.1	744.7	29.64
1411	11.24	11.29	7.29	7.21	733.4	743.0	29.56
1412	11.26	11.31	7.29	7.21	731.8	741.4	29.50
1413	11.25	11.30	7.29	7.21	732.4	741.9	29.52
1414	11.27	11.32	7.29	7.22	732.2	741.8	29.52
1415	11.24	11.29	7.29	7.21	730.0	739.6	29.43
1416	11.27	11.32	7.29	7.21	727.0	736.5	29.31
1417	11.26	11.30	7.29	7.21	727.2	736.7	29.31
1418	11.27	11.31	7.29	7.21	726.7	736.1	29.29
1419	11.26	11.31	7.29	7.21	726.9	736.4	29.30
1420	11.25	11.30	7.29	7.22	727.2	736.7	29.32
1421	11.25	11.30	7.29	7.21	723.9	733.4	29.18
1422	11.25	11.30	7.29	7.21	723.4	732.8	29.16
1423	11.26	11.31	7.29	7.21	724.1	733.5	29.19
Average	11.24	11.29	7.27	7.19	736.45	746.11	29.69

NOx_CEM_Data.xls: run3

SECOR
ANALYZER CALIBRATION DATA

CLIENT: McMinnville Electric
LOCATION: McMinnville, Tennessee
SOURCE I.D.: Engine Exhaust
OPERATOR: DW, BE

DATE: November 28, 2006
INITIAL CAL ITIME:
FINAL CAL TIME:

O_2 Method 3A							
INITIAL SYSTEM CALIBRATION		Cal Gas Range (% of Span)	Actual Cylinder Value (%)	Instrument Response (%)	Absolute Difference (%)	Actual Difference (%)	Allowed Difference (%)
Span Value: 25							
Model No: CAI 300	ZERO	N_2 or Air	0.00	0.00	0.00	0.0	2
Serial No: R08095	MID-RANGE	40 - 60%	12.50	12.53	0.03	0.1	2
	HIGH-RANGE	80 - 100%	20.00	20.02	0.02	0.1	2
FINAL SYSTEM CALIBRATION							
	ZERO	N_2 or Air	0.00	0.03	0.03	0.1	2
	MID-RANGE	40 - 60%	12.50	12.50	0.00	0.0	2
	HIGH-RANGE	80 - 100%	20.00	20.00	0.00	0.0	2

CO_2 Method 3A							
INITIAL SYSTEM CALIBRATION		Cal Gas Range (% of Span)	Actual Cylinder Value (%)	Instrument Response (%)	Absolute Difference (%)	Actual Difference (%)	Allowed Difference (%)
Span Value: 25							
Model No: CAI 300	ZERO	N_2 or Air	0.00	0.00	0.00	0.0	2
Serial No: R08095	MID-RANGE	40 - 60%	12.40	12.40	0.00	0.0	2
	HIGH-RANGE	80 - 100%	19.70	19.70	0.00	0.0	2
FINAL SYSTEM CALIBRATION							
	ZERO	N_2 or Air	0.00	0.12	0.12	0.5	2
	MID-RANGE	40 - 60%	12.40	12.51	0.11	0.4	2
	HIGH-RANGE	80 - 100%	19.70	19.83	0.13	0.5	2

NO_x Method 7E							
INITIAL SYSTEM CALIBRATION		Cal Gas Range (% of Span)	Actual Cylinder Value (ppm)	Instrument Response (ppm)	Absolute Difference (ppm)	Actual Difference (%)	Allowed Difference (%)
Span Value: 1000							
Model No: TEI 42H	ZERO	N_2 or Air	0.00	1.18	1.18	0.1	2
Serial No: 42H-50850-286	MID-RANGE	40 - 60%	500.80	504.90	4.10	0.4	2
	HIGH-RANGE	80 - 100%	988.60	991.50	2.90	0.3	2
FINAL SYSTEM CALIBRATION							
	ZERO	N_2 or Air	0.00	0.54	0.54	0.1	2
	MID-RANGE	40 - 60%	500.80	503.50	2.70	0.3	2
	HIGH-RANGE	80 - 100%	988.60	986.70	1.90	0.2	2

JM 11-30-06

NOx_CEM_Data.xls: CALS

SECOR
CEMS BIAS DATA

CLIENT: McMinnville Electric
LOCATION: McMinnville, Tennessee
SOURCE I.D.: Engine Exhaust

DATE: November 28, 2006
OPERATOR: DW, BE

O_2 Method 3A

	Instrument Response (%)	Pre Test CEMS Response (%)	Pre Test Calibration Bias (%)	Post Test CEMS Response (%)	Post Test Calibration Bias (%)	Allowed Bias (%)	Calibration Drift (%)	Allowed Drift (%)
Span Value: 25				Run 1				
ZERO	0.00	0.04 ✓	0.2	0.03 ✓	0.1	5	0.0	3
BIAS GAS	20.02	19.94 ✓	0.3	19.89 ✓	0.5	5	0.2	3
				Run 2				
ZERO	0.00	0.03	0.1	0.05 ✓	0.2	5	0.1	3
BIAS GAS	20.02	19.89	0.5	19.86 ✓	0.6	5	0.1	3
				Run 3				
ZERO	0.00	0.05	0.2	0.05 ✓	0.2	5	0.0	3
BIAS GAS	20.02	19.86	0.6	19.89 ✓	0.5	5	0.1	3

CO_2 Method 3A

	Instrument Response (%)	Pre Test CEMS Response (%)	Pre Test Calibration Bias (%)	Post Test CEMS Response (%)	Post Test Calibration Bias (%)	Allowed Bias (%)	Calibration Drift (%)	Allowed Drift (%)
Span Value: 25				Run 1				
ZERO	0.00	0.00 ✓	0.0	0.02 ✓	0.1	5	0.1	3
BIAS GAS	19.70	19.66 ✓	0.2	19.65 ✓	0.2	5	0.0	3
				Run 2				
ZERO	0.00	0.02	0.1	0.12 ✓	0.5	5	0.4	3
BIAS GAS	19.70	19.65	0.2	19.64 ✓	0.2	5	0.0	3
				Run 3				
ZERO	0.00	0.12	0.5	0.14 ✓	0.6	5	0.1	3
BIAS GAS	19.70	19.64	0.2	19.73 ✓	0.1	5	0.4	3

NO_x Method 7E

	Instrument Response (ppm)	Pre Test CEMS Response (ppm)	Pre Test Calibration Bias (%)	Post Test CEMS Response (ppm)	Post Test Calibration Bias (%)	Allowed Bias (%)	Calibration Drift (%)	Allowed Drift (%)
Span Value: 1000				Run 1				
ZERO	1.18	6.31 ✓	0.5	5.85 ✓	0.5	5	0.0	3
BIAS GAS	991.50	978.20 ✓	1.3	974.60 ✓	1.7	5	0.4	3
				Run 2				
ZERO	1.18	5.85	0.5	2.00 ✓	0.1	5	0.4	3
BIAS GAS	991.50	974.60	1.7	971.40 ✓	2.0	5	0.3	3
				Run 3				
ZERO	1.18	2.00	0.1	5.70 ✓	0.5	5	0.4	3
BIAS GAS	991.50	971.40	2.0	977.70 ✓	1.4	5	0.6	3

JM 11-30-06

NOx_CEM_Data.xls: Bias Data R 1-3

SECOR
ANALYZER CALIBRATION DATA

CLIENT: McMinnville Electric
LOCATION: McMinnville, Tennesse
SOURCE I.D.: Engine Exhaust
OPERATOR: DW, BE

DATE: November 16, 2006
INITIAL CAL ITIME:
FINAL CAL TIME:

O_2 Method 3A

INITIAL SYSTEM CALIBRATION		Cal Gas Range (% of Span)	Actual Cylinder Value (%)	Instrument Response (%)	Absolute Difference (%)	Actual Difference (%)	Allowed Difference (%)
Span Value: 25							
Model No: CAT 300	ZERO	N_2 or Air	0.00	0.00	0.00	0.0	2
Serial No: R05C05	MID-RANGE	40 - 60%	12.50	12.53	0.03	0.1	2
	HIGH-RANGE	80 - 100%	20.00	20.02	0.02	0.1	2
FINAL SYSTEM CALIBRATION							
	ZERO	N_2 or Air	0.00	0.03	0.03	~~0.03~~ 0.1	2
	MID-RANGE	40 - 60%	12.50	12.50	~~12.5~~ 0.0	0.0	2
	HIGH-RANGE	80 - 100%	20.00	20.00	~~20.00~~ 0.0	0.0	2

CO_2 Method 3A

INITIAL SYSTEM CALIBRATION		Cal Gas Range (% of Span)	Actual Cylinder Value (%)	Instrument Response (%)	Absolute Difference (%)	Actual Difference (%)	Allowed Difference (%)
Span Value: 25							
Model No: CAT	ZERO	N_2 or Air	0.00	0.00	0.00	0.0	2
Serial No: R05C05	MID-RANGE	40 - 60%	12.40	12.40	0.00	0.0	2
	HIGH-RANGE	80 - 100%	19.70	19.70	0.00	0.0	2
FINAL SYSTEM CALIBRATION							
	ZERO	N_2 or Air	0.00	0.12	0.12	0.5	2
	MID-RANGE	40 - 60%	12.40	12.51	0.11	0.4	2
	HIGH-RANGE	80 - 100%	19.70	19.83	0.13	0.5	2

NO_x Method 7E

INITIAL SYSTEM CALIBRATION		Cal Gas Range (% of Span)	Actual Cylinder Value (ppm)	Instrument Response (ppm)	Absolute Difference (ppm)	Actual Difference (%)	Allowed Difference (%)
Span Value: 100							
Model No: TET 42H	ZERO	N_2 or Air	0.00	1.18 ~~0.65~~	~~0.65~~ 1.18	~~0.1~~ 0.1	2
Serial No: 1214-50590-256	MID-RANGE	40 - 60%	~~500.9~~ ~~44.10~~	~~514.9~~ ~~44.60~~	~~0.70~~ 4.10	~~0.1~~ 0.4	2
	HIGH-RANGE	80 - 100%	~~89.60~~	~~991.5~~ ~~89.32~~	~~0.25~~ 2.90	~~0.3~~ 0.3	2
FINAL SYSTEM CALIBRATION							
	ZERO	N_2 or Air	0.00	0.54	0.54	0.1	2
	MID-RANGE	40 - 60%	~~44.10~~	503.5	2.70	0.3	2
	HIGH-RANGE	80 - 100%	~~89.60~~	998.7	1.90	0.2	2

NOx_CEM_Data.xls: CALS

SECOR
CEMS BIAS DATA

CLIENT: McMinnville Electric
LOCATION: McMinnville, Tennessee
SOURCE I.D.: Engine Exhaust

DATE: November 16, 2006
OPERATOR: DW, BE

O_2 Method 3A

Span Value: 25	Instrument Response (%)	Pre Test CEMS Response (%)	Pre Test Calibration Bias (%)	Post Test CEMS Response (%)	Post Test Calibration Bias (%)	Allowed Bias (%)	Calibration Drift (%)	Allowed Drift (%)
			Run 1					
ZERO	0.00	0.04	0.2	0.03	0.1	5	0.0	3
BIAS GAS	20.02	19.94	0.3	19.84	0.5	5	0.2	3
			Run 2					
ZERO		0.03	0.1	0.05	0.2	5	0.1	3
BIAS GAS		19.89	0.5	19.86	0.6	5	0.1	3
			Run 3					
ZERO		0.05	0.2	0.05	0.2	5	0.0	3
BIAS GAS		19.80	0.6	19.89	0.5	5	0.1	3

CO_2 Method 3A

Span Value: 25	Instrument Response (%)	Pre Test CEMS Response (%)	Pre Test Calibration Bias (%)	Post Test CEMS Response (%)	Post Test Calibration Bias (%)	Allowed Bias (%)	Calibration Drift (%)	Allowed Drift (%)
			Run 1					
ZERO	0.00	0.08	0.0	0.02	0.1	5	0.1	3
BIAS GAS	19.90	19.66	0.2	19.65	0.2	5	0.0	3
			Run 2					
ZERO		0.02	0.1	0.12	0.5	5	0.4	3
BIAS GAS		19.65	0.2	19.64	0.2	5	0.0	3
			Run 3					
ZERO		0.12	0.5	0.14	0.0	5	0.1	3
BIAS GAS		19.64	0.2	19.73	0.1	5	0.4	3

NO_x Method 7E

Span Value: 100	Instrument Response (ppm)	Pre Test CEMS Response (ppm)	Pre Test Calibration Bias (%)	Post Test CEMS Response (ppm)	Post Test Calibration Bias (%)	Allowed Bias (%)	Calibration Drift (%)	Allowed Drift (%)
			Run 1					
ZERO	~~0.0~~ 1.18	~~0.16~~ 0.31	~~0.1~~ 0.5	5.85	0.5	5	0.0	3
BIAS GAS	~~329.5~~ 329.5	~~326.2~~ 329.8	~~326.5~~ 326.5	974.6	1.7	5	0.4	3
			Run 2					
ZERO		5.85	0.5	2.00	0.1	5	0.4	3
BIAS GAS		974.6	1.7	971.4	2.0	5	0.3	3
			Run 3					
ZERO		2.00	0.1	5.7	0.5	5	0.4	3
BIAS GAS		971.4	2.0	977.7	1.4	5	0.6	3

NOx_CEM_Data.xls: Bias Data R 1-3

DAY	Time	CO2	O2	NOx	
332	728	0.18865	20.854	-0.1372	
332	729	0.19477	20.83	-0.1372	
332	730	0.19093	20.832	-0.14063	
332	731	0.19122	20.83	-0.1029	
332	732	0.19265	20.755	-0.1372	
332	733	0.1392	0.44274	-0.15549	
332	734	0.00171	0.02887	-0.24696	
332	735	-0.00229	0.00286	0.04802	
332	736	12.044	13.338	0.06517	
332	737	19.13	19.983	0.05945	
332	738	19.704	20.022	0.05831	
332	739	15.754	16.104	0.04459	
332	740	12.396	12.53	0.06059	
332	741	12.262	12.631	0.05373	
332	742	0.07117	0.45275	57.678	
332	743	0.01429	0.04659	100.11	
332	744	0.006	0.03173	100.11	
332	745	0.00543	-0.00715	100.14	
332	746	0.00029	0.01229	100.12	
332	747	0	0.02258	100.11	
332	748	0.00171	0.01515	99.709	
332	749	-0.00314	0.00114	94.167	
332	750	-0.00286	0.01286	93.126	
332	751	-0.00086	-0.00029	89.953	
332	752	0	-0.01772	89.323	
332	753	0.00857	0.29755	80.883	
332	754	-0.00286	0.01458	44.796	
332	755	-0.00257	0.01858	43.517	
332	756	0	-0.00114	47.515	
332	757	0.002	-0.00029	48.559	52.29 NO2 NOx Conv Eff. Ck
332	758	-0.00114	0.20951	48.399	92.86 %
332	759	0.00286	0.11004	41.928	
332	800	-0.004	0.1129	44.181	
332	801	-0.00257	0.10347	44.513	
332	802	0.00086	0.12062	44.7	
332	803	-0.00486	0.1089	44.804	
332	804	-0.00114	0.12548	44.925	
332	805	0.03144	16.356	36.746	
332	806	0.01572	7.4148	1.8579	
332	807	-0.00171	0.0383	0.27441	
332	808	-0.00114	0.03602	0.16351	

NOx_CEM_Data.xls: Raw Data

DAY	Time	CO2	O2	NOx
332	809	14.689	14.992	0.15664
332	810	19.631	19.899	0.0686
332	811	19.661	19.94	0.05031
332	812	16.336	16.565	0.53284
332	813	0.91354	0.82525	48.199
332	814	0.03087	0.0646	87.638
332	815	0.01458	0.01915	88.496
332	816	0.01115	4.1147	88.076
332	817	0.04859	20.721	33.964
332	818	0.04774	20.891	0.25042
332	819	0.04545	20.872	0.12464
332	911	7.1685	11.336	756.65
332	912	7.1569	11.341	757.07
332	913	7.16	11.338	757.96
332	914	3.9712	6.5768	742.94
332	915	0.00286	0.0243	160.24
332	916	-0.00772	0.0203	1.1778
332	917	-0.01344	0.12007	14.842
332	918	-0.0203	0.07147	782.93
332	919	-0.01601	0.04745	996.67
332	920	-0.01858	0.07089	997.67
332	921	-0.01744	0.04088	983.05
332	922	-0.01829	0.05403	982.33
332	923	-0.02287	0.05574	991.52
332	924	-0.01858	0.05574	897.52
332	925	-0.01972	0.04002	510.15
332	926	-0.02344	0.04402	504.92
332	927	5.0012	8.0619	548.44
332	928	1.8242	2.9123	608.69
332	929	0.00086	0.05945	52.457
332	930	-0.00229	0.0363	6.3112
332	931	-0.00286	0.07889	10.462
332	932	-0.00143	0.12605	602.84
332	933	-0.00171	0.12176	977.67
332	934	-0.00457	0.13005	978.17
332	935	4.5906	7.3062	945.84
332	936	7.1354	11.306	765.94
332	937	7.1419	11.275	752.3
332	938	7.1494	11.299	753.87
332	939	7.1529	11.269	752.7
332	940	7.1549	11.294	751.97

NOx_CEM_Data.xls: Raw Data

DAY	Time	CO2	O2	NOx			
332	941	7.1536	11.276	751.42			
332	942	5.9955	12.811	681.06			
332	943	2.8809	16.919	80.627			
332	944	0.24696	20.492	14.131			
332	945	0.2058	20.628	15.012			
332	946	0.04802	20.805	2.8583			
332	947	0.39615	11.596	1.7721			
332	948	6.8559	10.804	319.65			
332	949	7.1557	11.291	738.84			Difference
332	950	7.1634	11.257	748.3			0.08
332	951	7.1676	11.276	749.28			
332	952	7.1691	11.287	750.83			
332	953	7.172	11.278	751.63			0.53
332	954	7.1674	11.277	749.58			
332	955	7.1617	11.293	744.98			-0.36
332	956	7.1503	11.332	739.5			
332	957	7.1517	11.335	737.37			-1.38
332	958	3.5836	16.14	679.13			
332	959	6.2726	12.554	355.01			
332	1000	7.1748	11.305	736.33			
332	1001	7.1701	11.309	751.58			
332	1002	7.1796	11.297	752.59			0.66
332	1003	7.1801	11.294	753.18			
332	1004	7.183	11.297	752.58			0.66
332	1005	7.1775	11.299	752.04			
332	1006	7.1692	11.306	748.93			0.17
332	1007	7.1743	11.316	745.45			
332	1008	6.9457	11.599	744.94	Avg =	747.665	-0.36
332	1009	1.0238	19.62	501.21			
332	1010	0.05602	20.832	27.781			
332	1011	0.05373	20.874	7.0995			
332	1012	0.04944	20.831	5.9792			
332	1013	0.04973	20.851	4.7673			
332	1014	0.04802	20.833	3.6241			
332	1015	0.04601	20.849	3.4411			
332	1016	0.04173	20.851	2.7552			
332	1017	0.0463	20.848	2.7209			
332	1018	0.03973	20.855	2.7324			
332	1019	0.03515	20.854	2.1493			
332	1020	0.0383	20.85	1.692			
332	1021	0.03773	20.854	1.7149			

NOx_CEM_Data.xls: Raw Data

DAY	Time	CO2	O2	NOx	
332	1022	0.7388	19.949	1.9206	
332	1023	6.7058	11.906	303.45	
332	1024	7.1566	11.293	728.61	
332	1025	7.1586	11.3	739.95	
332	1026	7.1603	11.308	740.91	
332	1027	7.1612	11.323	740.16	
332	1028	7.1599	11.3	736.71	Run 1
332	1029	7.1553	11.346	735.22	
332	1030	7.1564	11.323	731.74	
332	1031	7.1573	11.331	732.61	
332	1032	7.1564	11.334	732.49	
332	1033	7.1571	11.32	731	
332	1034	7.1541	11.318	730.18	
332	1035	7.1557	11.326	728.31	
332	1036	7.1559	11.334	726.6	
332	1037	7.156	11.333	726.82	
332	1038	7.1575	11.328	725.04	
332	1039	7.1551	11.336	725.25	
332	1040	7.1643	11.324	725.57	
332	1041	7.1658	11.338	724.64	
332	1042	7.1611	11.311	726.17	
332	1043	7.1551	11.303	726.5	
332	1044	7.1577	11.298	726.43	
332	1045	7.1685	11.328	725.72	
332	1046	7.1657	11.354	724.85	
332	1047	7.1606	11.329	725	
332	1048	7.161	11.325	727.54	
332	1049	7.1592	11.318	726.73	
332	1050	7.1567	11.339	728.25	
332	1051	7.1669	11.332	727.66	
332	1052	7.1673	11.319	727.12	
332	1053	7.1697	11.323	727.33	
332	1054	7.1668	11.321	727.94	
332	1055	7.1699	11.327	728.41	
332	1056	7.1762	11.296	729.37	
332	1057	7.1745	11.28	729.46	
332	1058	7.1745	11.316	730.61	
332	1059	7.1775	11.309	732.88	
332	1100	7.1756	11.324	732.46	
332	1101	7.1817	11.309	731.64	
332	1102	7.1807	11.302	731.69	

NOx_CEM_Data.xls: Raw Data

DAY	Time	CO2	O2	NOx
332	1103	7.1802	11.298	735.52
332	1104	7.1825	11.297	735.9
332	1105	7.1891	11.304	735.42
332	1106	7.1897	11.283	735.13
332	1107	7.1932	11.278	736.47
332	1108	7.2038	11.27	735.7
332	1109	7.1945	11.289	736.3
332	1110	7.2007	11.279	738.27
332	1111	7.1955	11.279	739.41
332	1112	7.1954	11.3	737.28
332	1113	7.1988	11.28	737.28
332	1114	7.2004	11.271	739.06
332	1115	7.2053	11.268	739.01
332	1116	7.2064	11.263	742.54
332	1117	7.2018	11.29	742.35
332	1118	7.2068	11.293	740.94
332	1119	7.2105	11.242	740.08
332	1120	7.2008	11.293	742.85
332	1121	7.2087	11.253	744.1
332	1122	7.2092	11.267	743.49
332	1123	7.2108	11.263	742.16
332	1124	7.2088	11.264	742.5
332	1125	7.2031	11.273	745.18
332	1126	7.1994	11.284	742.1
332	1127	7.2031	11.271	740.67
332	1128	6.391	10.031	739.58
332	1129	0.37973	0.49945	389.98
332	1130	0.02886	0.04086	14.001
332	1131	0.01914	0.02914	7.2804
332	1132	1.8267	1.9533	5.8517
332	1133	19.171	19.482	4.8802
332	1134	19.654	19.893	3.7487
332	1135	16.746	16.97	7.0974
332	1136	0.82918	0.78432	504.68
332	1137	0.05886	0.07058	962.31
332	1138	0.038	0.06886	974.6
332	1139	1.0466	1.6238	978.32
332	1140	7.0969	11.108	855.52
332	1141	7.1955	11.257	747.93
332	1142	7.2055	11.247	743.27
332	1143	7.1975	11.276	742.2

NOx_CEM_Data.xls: Raw Data

DAY	Time	CO2	O2	NOx	
332	1144	7.1987	11.268	741.4	
332	1145	7.206	11.271	740.55	
332	1146	7.1994	11.262	739.32	
332	1147	7.2029	11.262	739.45	
332	1148	7.2058	11.266	739.93	
332	1149	7.2057	11.257	739.34	
332	1150	7.2057	11.243	739.18	
332	1151	7.2034	11.266	739.4	
332	1152	7.1948	11.255	739.28	
332	1153	5.3953	13.714	732.91	
332	1154	0.12886	20.803	249.11	
332	1155	0.07858	20.842	8.309	
332	1156	0.06972	20.834	6.046	
332	1157	0.67802	20.055	4.9716	
332	1158	7.0165	11.467	339.49	
332	1159	7.1993	11.237	726.58	
332	1200	7.1914	11.284	738.76	Run 2
332	1201	7.1913	11.241	740.6	
332	1202	7.1996	11.257	740.98	
332	1203	7.2034	11.241	740.7	
332	1204	7.2023	11.243	740.56	
332	1205	7.1932	11.25	742.86	
332	1206	7.2001	11.254	744.51	
332	1207	7.1927	11.255	744.93	
332	1208	7.192	11.273	743.24	
332	1209	7.1907	11.254	742.99	
332	1210	7.1909	11.276	743.71	
332	1211	7.1921	11.263	741.33	
332	1212	7.192	11.257	741.9	
332	1213	7.191	11.263	740.96	
332	1214	7.1911	11.252	739.9	
332	1215	7.1843	11.261	740.5	
332	1216	7.1906	11.284	739.46	
332	1217	7.1929	11.248	738.66	
332	1218	7.1951	11.255	738.01	
332	1219	7.2002	11.253	737.36	
332	1220	7.1945	11.262	736.65	
332	1221	7.1892	11.266	736.77	
332	1222	7.1916	11.264	734.75	
332	1223	7.1917	11.268	733.64	
332	1224	7.1868	11.292	734.69	

NOx_CEM_Data.xls: Raw Data

DAY	Time	CO2	O2	NOx
332	1225	7.1839	11.276	734.3
332	1226	7.1842	11.26	733.49
332	1227	7.1907	11.269	731.99
332	1228	7.1899	11.267	731.01
332	1229	7.1843	11.264	730.24
332	1230	7.1817	11.28	731.77
332	1231	7.1815	11.276	731.14
332	1232	7.1809	11.272	730.18
332	1233	7.1902	11.266	728.87
332	1234	7.1911	11.258	727.99
332	1235	7.1886	11.265	728.66
332	1236	7.1917	11.26	729.7
332	1237	7.1929	11.257	729.93
332	1238	7.1983	11.258	728.63
332	1239	7.19	11.27	728.73
332	1240	7.1885	11.27	728.78
332	1241	7.1916	11.272	728.36
332	1242	7.1904	11.257	727.93
332	1243	7.1959	11.261	728.09
332	1244	7.2007	11.277	727.33
332	1245	7.2004	11.267	727.9
332	1246	7.2	11.268	728.01
332	1247	7.2014	11.273	727.21
332	1248	7.1985	11.265	727.77
332	1249	7.2003	11.28	728.32
332	1250	7.208	11.268	728.88
332	1251	7.2105	11.248	728.31
332	1252	7.2135	11.272	728.78
332	1253	7.2087	11.261	729.62
332	1254	7.212	11.262	730.1
332	1255	7.2158	11.247	728.95
332	1256	7.2163	11.257	729.42
332	1257	7.2189	11.256	730.73
332	1258	7.2189	11.259	729.75
332	1259	7.2251	11.254	729.48
332	1300	6.8212	10.641	728.82
332	1301	0.73222	1.0176	801.45
332	1302	0.10485	0.06114	960.07
332	1303	0.09772	0.06715	969.29
332	1304	2.2152	2.2576	971.4
332	1305	19.2	19.468	490.11

NOx_CEM_Data.xls: Raw Data

DAY	Time	CO2	O2	NOx	
332	1306	19.635	19.864	7.166	
332	1307	16.953	17.12	2.743	
332	1308	1.0889	0.89604	2.743	
332	1309	0.12258	0.04857	2.6973	
332	1310	0.20601	0.16973	2.0002	
332	1311	6.6273	10.285	284.8	
332	1312	7.2295	11.234	728.85	
332	1313	7.238	11.241	736.56	
332	1314	7.2507	11.233	736.06	
332	1315	7.2484	11.235	736.97	
332	1316	7.253	11.225	737.51	
332	1317	7.2478	11.238	737	
332	1318	1.7342	18.722	565.53	
332	1319	0.14891	20.841	31.85	
332	1320	0.14234	20.818	5.8308	
332	1321	3.335	16.56	32.184	
332	1322	7.2295	11.236	588.33	
332	1323	7.2466	11.242	731.1	
332	1324	7.2442	11.236	737.11	Run 3
332	1325	7.2491	11.253	738.09	
332	1326	7.2467	11.217	739.16	
332	1327	7.2424	11.242	739.13	
332	1328	7.2484	11.23	740.19	
332	1329	7.2451	11.238	740.49	
332	1330	7.2357	11.245	741.22	
332	1331	7.2407	11.238	741.46	
332	1332	7.2406	11.236	741.55	
332	1333	7.246	11.228	740.93	
332	1334	7.2473	11.248	740.64	
332	1335	7.2469	11.23	740.69	
332	1336	7.249	11.236	740.51	
332	1337	7.2469	11.236	740.56	
332	1338	7.2514	11.228	739.35	
332	1339	7.2548	11.233	740.28	
332	1340	7.2586	11.256	741.04	
332	1341	7.2581	11.231	740.28	
332	1342	7.2594	11.237	739.98	
332	1343	7.2617	11.235	739.96	
332	1344	7.2725	11.231	739.09	
332	1345	7.2637	11.241	738.89	
332	1346	7.2619	11.238	738.79	

NOx_CEM_Data.xls: Raw Data

DAY	Time	CO2	O2	NOx
332	1347	7.2624	11.243	737.3
332	1348	7.2628	11.24	736.96
332	1349	7.2677	11.233	737.29
332	1350	7.2729	11.239	737.62
332	1351	7.2745	11.235	738.23
332	1352	7.2749	11.231	738.22
332	1353	7.2732	11.241	737.94
332	1354	7.2804	11.231	739.41
332	1355	7.2857	11.231	738.64
332	1356	7.2883	11.221	737.68
332	1357	7.2824	11.244	738.08
332	1358	7.2846	11.238	738.49
332	1359	7.2849	11.24	737.56
332	1400	7.2862	11.238	737.92
332	1401	7.289	11.234	736.77
332	1402	7.2856	11.249	737.91
332	1403	7.289	11.221	737.97
332	1404	7.2875	11.243	737.1
332	1405	7.2841	11.245	738.12
332	1406	7.2892	11.247	738.23
332	1407	7.2914	11.25	736.68
332	1408	7.2868	11.25	736.16
332	1409	7.2872	11.25	736.33
332	1410	7.2892	11.256	735.11
332	1411	7.2903	11.24	733.37
332	1412	7.2903	11.259	731.8
332	1413	7.2863	11.249	732.36
332	1414	7.2921	11.267	732.19
332	1415	7.2906	11.241	730.02
332	1416	7.2877	11.269	727.04
332	1417	7.29	11.256	727.19
332	1418	7.289	11.265	726.65
332	1419	7.2908	11.262	726.91
332	1420	7.2923	11.247	727.21
332	1421	7.2873	11.253	723.93
332	1422	7.2883	11.251	723.39
332	1423	7.2857	11.26	724.11
332	1424	7.2879	11.252	724.62
332	1425	3.2395	4.883	648.51
332	1426	0.14783	0.04604	89.853
332	1427	0.12867	0.01515	7.6175

NOx_CEM_Data.xls: Raw Data

DAY	Time	CO2	O2	NOx
332	1428	0.13782	0.05433	5.6957
332	1429	16.509	16.674	4.8607
332	1430	19.734	19.894	3.9686
332	1431	16.311	16.427	7.3997
332	1432	0.9324	0.79944	515.16
332	1433	0.16641	0.09864	960.06
332	1434	0.14238	0.06891	973.38
332	1435	0.6976	1.0516	977.7
332	1436	0.75446	14.166	602.82
332	1437	0.12693	0.05947	735.16
332	1438	0.12493	0.05975	983.05
332	1439	0.12664	0.0566	986.65
332	1440	0.12693	0.08233	887.44
332	1441	0.12407	0.05603	510.6
332	1442	0.11864	0.03802	503.48
332	1443	15.567	15.733	417.27
332	1444	19.83	20.001	12.601
332	1445	16.136	16.316	0.67466
332	1446	12.512	12.5	0.66322
332	1447	12.507	12.509	0.68607
332	1448	2.4627	2.4376	0.54886
332	1449	0.12263	0.02944	0.53741

NOx_CEM_Data.xls: Raw Data

Moisture and Volumetric Flow Rate Calculations

Client: McMinnville Electric — Location: McMinnville, TN

Source: Engine Exhaust — Date: November 28, 2006

	Run 1	Run 2	Run 3	Run 4	Average
Time Began	10:27	12:00	13:24		----
Time Ended	11:27	13:00	14:24		----
Sample Time, min	60	60	60		60
Barometric Pressure, P_{bar} (in. Hg)	29.10	29.10	29.05		29.08
Dry Gas Meter I.D.	1	1	1		1
Meter Corr. Factor, Y	0.955	0.955	0.955		0.955
Meter $DH_@$	1.994	1.994	1.994		1.994
Pitot Coefficient, C_p	0.84	0.84	0.84		0.84
Duct Diameter, in.	15.75	15.75	15.75		15.75
Duct Area (A_s), ft^2	1.35	1.35	1.35		1.35
Stack Gas					
Temperature, °F	633.3	632.8	639.0		635.0
O_2 Concentration, %	11.3	11.3	11.3		11.3
CO_2 Concentration, %	7.2	7.2	7.2		7.2
Static Pressure, P_g	1.90	2.20	2.70		2.27
Stack Pressure, P_s	29.24	29.26	29.25		29.25
Moisture Calculations					
Meter Volume, ft^3	34.185	30.665	34.100		32.983
Avg. Dry Gas Meter Temp. (°F)	77.5	84.4	84.4		82.1
H_20 Gain, V_{lc}	59.3	59.4	56.2		58.3
Avg. DH	1.0	1.0	1.0		1.0
Meter Pressure, in. Hg	29.17	29.17	29.12		29.16
Standard Meter Volume, ft^3 (Vm_{std})	31.300	27.720	30.773		29.931
Standard Water Volume, ft^3 (Vw_{std})	2.791	2.796	2.645		2.744
Moisture Fraction, Saturation	1.0000	1.0000	1.0000		1.0000
Moisture Fraction, Measured	0.0819	0.0916	0.0792		0.0842
Applicable Moisture (lower Sat. vs. Me	0.0819	0.0916	0.0792		0.0842
Volumetric Flow Rate					
Avg. SQRT DP	1.9342	1.9615	1.9238		1.9398
Mol. Wt. Stack Gas, (Md)	29.60	29.60	29.60		29.60
Mol. Wt. Stack Gas, (M_s)	28.65	28.54	28.68		28.62
Velocity, (V_s)	158.67	161.13	158.12		159.30
At Stack Conditions, acfm (Q_a)	12,880	13,080	12,836		12,932
At Wet Standard Conditions[a], wscfm ((	6,081	6,183	6,030		6,098
At Standard Conditions[a], dscfm (Q_s)	5,581	5,615	5,551		5,582

[a]68 °F, 29.92 in. Hg.

11-30-06

Eng_Exh_RM4.xls: PMTBL

SECOR

RM 1 PARTICULATE VELOCITY TRAVERSE - FIELD SAMPLING DATA

Plant:	McMinnville Electric	Stack Dia.:	15.75		
Location:	McMinnville, TN	Port Dia.:	0.75		
Source I.D.:	Engine Exhaust	Port Depth:	1.25		
Date:	November 28, 2006	Upstream **A** (in):	58.5	Diameters:	3.7
Operator(s):	DW, BE	Downstrean **B** (in):	131.5	Diameters:	8.3

Number of Traverse Points on a Diameter

	Diameter					
Point No.	**2**	**4**	**6**	**8**	**10**	**12**
1	14.6	6.7	4.4	3.2	2.6	2.1
2	85.4	25.0	14.6	10.5	8.2	6.7
3		75.0	29.6	19.4	14.6	11.8
4		93.3	70.4	32.3	22.6	17.7
5			85.4	67.7	34.2	25.0
6			95.6	80.6	65.6	35.6
7				89.5	77.4	64.4
8				96.8	85.4	75.0
9					91.8	82.3
10					97.4	88.2
11						93.3
12						97.9

Point Number	Distance From Wall	Distance with Port
1	1.1	2.3
2	3.9	5.2
3	11.8	13.1
4	14.7	15.9

Sketch Stack and Port Dimensions Here:

SAMPLE DATA FORM

Plant:	McMinnville Electric	Filter ID:	N/A
Location:	McMinnville, TN	Ambient Temp. (°F):	68
Source I.D.:	Engine Exhaust	Baro. Press. (in. Hg):	29.1
Date:	November 28, 2006	Static Press. (in H_2O):	1.9
Flow Traverse Time:	10:16	O_2 (%):	11.34
Run No.:	EE-RM4-R1	CO_2 (%):	7.19
Operators:	DW, BE	Duct Dia. (in):	15.75
Meter Box I.D.:	1	B_{ws} (assumed):	N/A
Meter Y:	0.9554	Nozzle Dia. (in):	N/A
Meter Delta H@:	1.9937	K Factor:	N/A
Probe I.D.:	2'/S-Type	Leak Check:	
Probe Length/Type:	2'/S-Type	Pre: 0.001 acf	10 in. Hg Vac.
Pitot Coeff. (Cp):	0.84	Post: 0.001 acf	8 in. Hg Vac.

Post-test Probe Visual Inspection Y N

Balance Ck Wt 1 kg = 998.9/999.2

Moisture

Imp.	Initial	Final
1	719.0	765.3
2	681.5	684.5
3	595.1	597.4
4	902.7	910.4
5		
Net Gain		59.3

Pitot:	Impact	Static	
Pre:	0	0	in. H_2O/15 sec
Post:	0	0	in. H_2O/15 sec

DGM Clock Time	Port/Point I.D.	Sample Time (min.)	DGM Reading (DACF)	ΔP (in. H_2O)	ΔH (in. H_2O)	Stack Temp. (F)	Probe Temp. (°F)	Filter Temp. (°F)	Imp. Outlet Temp. (°F)	Filter Temp. Exit (°F)	DGM Temp. (°F)		Vacuum (in. Hg)
10:27	A/1	0	268.700	3.70	1.0	640			69		73	73	4.5
	2	10	274.250	4.15	1.0	642			62		76	74	4.5
	3	20	280.040	3.90	1.0	627			60		79	74	4.5
	4	30	285.730	3.20	1.0	622			58		81	76	4.5
	B/1	40	291.430	3.50	1.0	639			58		84	77	5.0
	2	50	297.140	4.10	1.0	641			58		85	78	
11:27	3	60	302.885	4.15		628							
	4			3.30		627							

Total Time	Vol. (DACF	Avg. √ΔP	Avg. ΔH	Avg. t_s
60	34.185	1.93	1.0	633

Average DGM Temp.	Max. Vac.
77.50	5.0

QC Check: JM 11-30-06
(Printout Only)

Field Team Leader Review
(Original Only)

SECOR

SAMPLE DATA FORM

Plant:	McMinnville Electric	Filter ID:	N/A
Location:	McMinnville, TN	Ambient Temp. (°F):	68
Source I.D.:	Engine Exhaust	Baro. Press. (in. Hg):	29.1
Date:	November 28, 2006	Static Press. (in H_2O):	2.2
Flow Traverse Time:	11:53	O_2(%):	11.32 ✓
Run No.:	EE-RM4-R2	CO_2(%):	7.17 ✓
Operators:	DW, BE	Duct Dia. (in):	15.75
Meter Box I.D.:	1	B_{ws} (assumed):	N/A
Meter Y:	0.9554	Nozzle Dia. (in):	N/A
Meter Delta H@:	1.9937	K Factor:	N/A
Probe I.D.:	2'/S-Type	Leak Check:	
Probe Length/Type:	2'/S-Type	Pre: 0 acf	8 in. Hg Vac.
Pitot Coeff. (Cp):	0.84	Post: 0 acf	8 in. Hg Vac.

Post-test Probe Visual Inspection Y N

Balance Ck Wt 1 kg = 999.2/999.2

Moisture

Imp.	Initial	Final
1	765.3	813.5
2	684.5	687.7
3	597.4	597.7
4	900.3	908.0
5		
Net Gain		59.4

Pitot:	Impact	Static	
Pre:	0	0	in. H_2O/15 sec
Post:	0	0	in. H_2O/15 sec

DGM Clock Time	Port/Point I.D.	Sample Time (min.)	DGM Reading (DACF)	ΔP (in. H_2O)	ΔH (in. H_2O)	Stack Temp. (F)	Probe Temp. (°F)	Filter Temp. (°F)	Imp. Outlet Temp. (°F)	Filter Temp. Exit (°F)	DGM Temp. (°F)		Vacuum (in. Hg)
12:00	A/1	0	303.200	3.50	1.0	641			67		83	80	3.5
	2	10	309.160	4.15	1.0	644			58		86	82	3.5
	3	20	314.890	4.05	1.0	626			58		86	81	3.5
	4	30	320.630	3.80	1.0	621			59		87	82	3.5
	B/1	40	326.350	3.80	1.0	643			61		89	83	3.5
	2	50	332.080	4.40	1.0	646			60		90	84	3.5
13:00	3	60	333.865	4.00		623							
	4			3.15		618							

Total Time	Vol. (DACF	Avg. √ΔP	Avg. ΔH	Avg. t_s [A]
60	30.665	1.96	1.0	633

Average DGM Temp.	Max. Vac.
84	3.5

QC Check Jm 11-30-06
(Printout Only)

Field Team Leader Review _____
(Original Only)

SECOR

SAMPLE DATA FORM

Balance Ck Wt 1 kg = 999.2/999.8

Plant:	McMinnville Electric	Filter ID:	N/A
Location:	McMinnville, TN	Ambient Temp. (°F):	68
Source I.D.:	Engine Exhaust	Baro. Press. (in. Hg):	29.05
Date:	November 28, 2006	Static Press. (in H_2O):	2.7
Flow Traverse Time:	13:16	O_2 (%):	11.29
Run No.:	EE-RM4-R1	CO_2 (%):	7.19
Operators:	DW, BE	Duct Dia. (in):	15.75
Meter Box I.D.:	1	B_{ws} (assumed):	N/A
Meter Y:	0.9554	Nozzle Dia. (in):	N/A
Meter Delta H@:	1.9937	K Factor:	N/A
Probe I.D.:	2'/S-Type	Leak Check:	
Probe Length/Type:	2'/S-Type	Pre: 0 acf	8 in. Hg Vac.
Pitot Coeff. (Cp):	0.84	Post: 0 acf	8 in. Hg Vac.

Moisture

Imp.	Initial	Final
1	813.5	861.4
2	687.3	690.4
3	597.7	597.7
4	908.0	913.2
5		
Net Gain		56.2

Pitot:	Impact	Static	
Pre:	0	0	in. H_2O/15 sec.
Post:	0	0	in. H_2O/15 sec.

Post-test Probe Visual Inspection Y N

DGM Clock Time	Port/Point I.D.	Sample Time (min.)	DGM Reading (DACF)	ΔP (in. H_2O)	ΔH (in. H_2O)	Stack Temp. (F)	Probe Temp. (°F)	Filter Temp. (°F)	Imp. Outlet Temp. (°F)	Filter Temp. Exit (°F)	DGM Temp. (°F)		Vacuum (in. Hg)
13:24	A/1	0	337.900	3.20	1.0	642			60		84	83	3.5
	2	10		4.05	1.0	645			48		86	82	3.5
	3	20	349.360	4.00	1.0	630			48		86	83	3.5
	4	30	355.030	3.20	1.0	618			48		86	83	3.5
	B/1	40	360.670	3.90	1.0	644			49		87	83	3.5
	2	50	366.430	4.25	1.0	647			48		87	83	3.5
14:24	3	60	372.000	3.90		645							
	4			3.20		641							

Total Time	Vol. (DACF)	Avg. √ΔP	Avg. ΔH	Avg. t_s
60	34.100	1.92	1.0	639

Average DGM Temp.	Max. Vac.
84.42	3.5

QC Check Jm 11-30-06
(Printout Only)

Field Team Leader Review
(Original Only)

SECOR

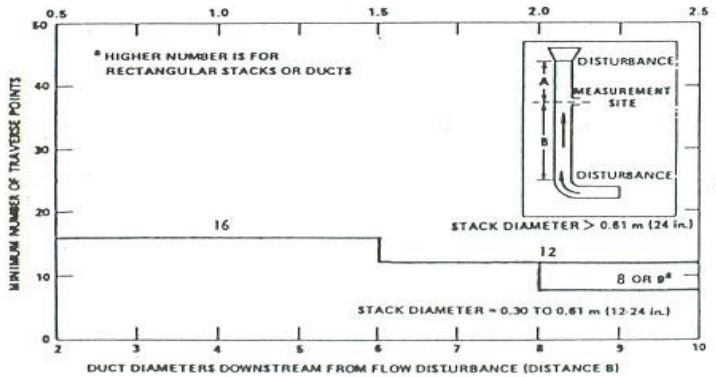
RM 1 VELOCITY TRAVERSE - FIELD SAMPLING DATA

Plant:	McMinnville Electric	Stack Dia.:	15 3/4
Location:	McMinnville TN	Port Dia.:	3/4"
Source I.D.:	Engine Exhaust	Port Depth:	1 1/4
Date:	11/27/06	Upstream **A** (in):	58 1/2
Operator(s):	DW JM	Downstream **B** (in):	131 1/2

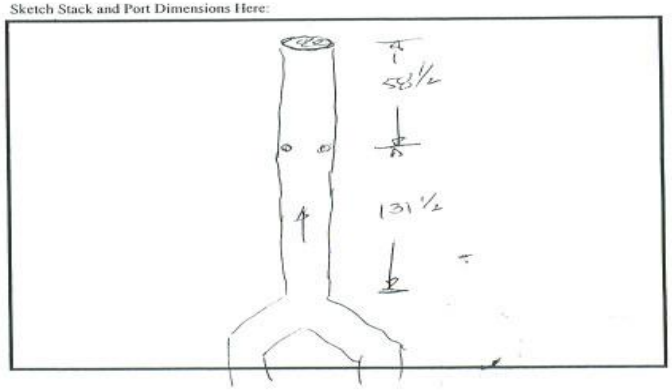
Number of Traverse Points on a Diameter

Point No.	Diameter 2	4	6	8	10	12
1	14.6	6.7	4.4	3.2	2.6	2.1
2	85.4	25.0	14.6	10.5	8.2	6.7
3		75.0	29.6	19.4	14.6	11.8
4		93.3	70.4	32.3	22.6	17.7
5			85.4	67.7	34.2	25.0
6			95.6	80.6	65.6	35.6
7				89.5	77.4	64.4
8				96.8	85.4	75.0
9					91.8	82.3
10					97.4	88.2
11						93.3
12						97.9

Point Number	Distance From Wall (in)	Distance with Port (in)
1	1.1	2.9
2	3.9	5.2
3	11.8	13.1
4	14.6	15.9



Sketch Stack and Port Dimensions Here:



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SECOR

CYCLONIC FLOW FIELD CALCULATION SHEET

Plant:	Mc Minnville Electric	Pitot ID:	2' / S-type
Location:	Mc Minnville, TN	Pitot Coef. (Cp):	0.84
Source I.D.:	Engine Exhaust	Ambient Temp. (°F):	66
Date:	11/26/08	Baro. Press. (in. Hg):	29.10
Operators:	DW BE	Base Time:	

Sample Point	Run No.				Run No.			
	Angle Φ	Test Time	ΔP	COS Φ $(\Delta P)^{0.5}$	Angle Φ	Test Time	ΔP	COS Φ $(\Delta P)^{0.5}$
A/1	2.5		0					
2	2							
3	0							
4	0							
B/1		not chosen per B. Parker w/ FTDAPC						
2								
3								
4								

Test Time = COS Φ (Base Time)

Average ΔPv | Average ΔPv

$$\text{Average } \Delta Pv = \frac{\Sigma \text{ COS } \Phi \ (DP)^{0.5}}{n}$$

H:\Admin\David West\Field Data Sheets\Secor M5 Data Sheet.xls
: Cyclonic Flow

SECOR

SAMPLE DATA FORM

Plant	McMinnville Electric	Filter ID	N/A
Location	McMinnville, TN	Ambient Temp (°F)	68
Source I.D.	EUG	Baro. Press. (in. Hg)	29.10
Date	11-28-06	Static Press. (in H_2O)	1.9
Flow Traverse Time	10:16	O_2 (%)	11.34
Run No.	EE-RM4-R1	CO_2 (%)	7.19
Operators	BE, DW	Duct Dia. (in)	15.75
Meter Box I.D.	1	B_{ws} (assumed)	N/A
Meter Y	0.9554	Nozzle Dia. (in)	N/A
Meter Delta H@	1.9937	K Factor	N/A
Probe I.D.	2/3 type	Leak Check:	
Probe Length/Type	24"	Pre 0.001 acf	10 in. Hg Vac
Pitot Coeff. (Cp)	0.87	Post 0.001 acf	5 in. Hg Vac
		Post-test Probe Visual Inspection	(Y) N

Balance Ck Wt 1 kg = 998.9 / 999.2

Moisture

Imp	Initial	Final
1	719.0	765.3
2	681.5	684.5
3	595.1	597.4
4	902.7	910.4
5		
Net Gain		54.3

Pitot	Impact	Static	
Pre	0.0	0.0	in H_2O 15 sec
Post	0.0	0.0	in H_2O 15 sec

DGM Check Time	Port/Point I.D.	Sample Time (min.)	DGM Reading (DACF)	ΔP (in H_2O)	ΔH (in H_2O)	Stack Temp (F)	Probe Temp (°F)	Filter Temp (°F)	Imp. Outlet Temp (°F)	Filter Temp. Exit (°F)	DGM Temp (°F)		Vacuum (in. Hg)
10:35	A/1	0	268.70	3.7	1.0	640	N/A	N/A	69	N/A	73	73	4.8
	2	10	274.25	4.15	1.0	642			65		76	74	4.5
	3	20	280.04	3.9	1.0	627			60		79	74	4.5
	4	30	285.93	3.2	1.0	622			58		81	76	4.5
	B/1	40	291.43	3.5	1.0	639			58		84	77	5.0
	2	50	297.14	4.1	1.0	641			58		85	78	
11:27	3	60	302.885	4.15	—	628							
	4			3.3		627							

Total Time	Vol. (DACF)	Avg. $\sqrt{\Delta P}$	Avg. ΔH	Avg. t_s
60	34.185	1.93	1.0	633

Average DGM Temp	Max. Vac.
77.50	5.0

QC Check _____
(Printout Only)

Field Team Leader Review _____
(Original Only)

SECOR

SAMPLE DATA FORM

Plant	McMinnville Electric	Filter ID	N/A
Location	McMinnville, TN	Ambient Temp (°F)	68
Source ID	Eng. Exhaust	Baro. Press. (in. Hg)	29.10
Date	11/29/06	Static Press. (in H_2O)	+2.2
Flow Traverse Time	1153	O_2 (%)	11.32
Run No.	Eng. RM4-R2	CO_2 (%)	7.17
Operators	DW, JE	Duct Dia. (in)	15 ¼
Meter Box I.D.	1	B_{ws} (assumed)	N/A
Meter Y	0.9551	Nozzle Dia. (in)	N/A
Meter Delta H@	1.6937	K Factor	N/A
Probe I.D.	2'/5' types	Leak Check	
Probe Length/Type	2'/5' types	Pre 0.00 acf 8 in. Hg Vac.	
Pitot Coeff. (Cp)	0.84	Post 0.00 acf 8 in. Hg Vac.	
		Post-test Probe Visual Inspection	(Y) N

Balance Clk Wt 1 kg = 999.2 / 999.2

Moisture

Imp	Initial	Final
1	765.2	813.5
2	684.8	687.7
3	597.4	598.7
4	900.3	909.8
5		
Net Gain		54.4

Pitot	Impact	Static	
Pre	0.0	0.0	in. H_2O 15 sec
Post	0.0	0.0	in. H_2O 15 sec

DGM Clock Time	Port/Point ID	Sample Time (min.)	DGM Reading (DACF)	ΔP (in. H_2O)	ΔH (in. H_2O)	Stack Temp (F)	Probe Temp (°F)	Filter Temp (°F)	Imp. Outlet Temp (°F)	Filter Temp. Exit (°F)	DGM Temp (°F)		Vacuum (in. Hg)
1200	A/1	0	303.200	3.5	1.0	644	N/A	N/A	67	N/A	83	80	3.5
	2	10	309.160	4.15	1.0	644			58		86	82	3.5
	3	20	314.89	4.05	1.0	626			55		86	81	3.5
	4	30	320.83	3.5	1.0	621			59		87	82	3.5
	B/1	40	326.35	3.8	1.0	643			61		89	83	3.5
	2	50	332.18	4.4	1.0	646			60		90	84	3.5
1300	3	60	337.865	4.0	—	623	—	—	—	—	—	—	—
	4			3.15		618							

Total Time	Vol. (DACF)	Avg. √ΔP	Avg. ΔH	Avg. t_s
60	30.665	1.96	1.0	633

Average DGM Temp.	Max. Vac.
84	3.5

QC Check _____
(Printout Only)

Field Team Leader Review _____
(Original Only)

10/18/04

Instrumetc Workbook-CIRC.xls: RM 5 RUN 1

SECOR

SAMPLE DATA FORM

Plant	McMinnville Electric	Filter ID	N/A
Location	McMinnville, TN	Ambient Temp. (°F)	68
Source ID	Eng. Exhaust	Baro. Press. (in Hg)	29.05
Date	11/26/08	Static Press. (in H_2O)	+2.7
Flow Traverse Time	1316	O_2 (%)	11.29
Run No.	EE-RM1-R3	CO_2 (%)	7.19
Operators	DW BE	Duct Dia. (in)	15 3/4
Meter Box ID	1	B_{ws} (assumed)	N/A
Meter Y	0.9554	Nozzle Dia. (in)	N/A
Meter Delta H@	1.9937	K Factor	N/A
Probe ID	2'/S Type	Leak Check	
Probe Length/Type	2'/S Type	Pre 0.0 cfm 8 in Hg Vac	
Pitot Coeff. (Cp)	0.84	Post 0.0 cfm 8 in Hg Vac	

Balance Ck Wt 1 kg = 999.2 / 999.8

Moisture

Imp	Initial	Final
1	817.3	861.4
2	687.3	690.7
3	797.7	797.7
4	903.5	913.2
5		
Net Gain		56.2

Pitot	Impact	Static	
Pre	0.0	0.0	in H_2O 15 sec
Post	0.0	0.0	in H_2O 15 sec

Post-test Probe Visual Inspection (Y) N

DGM Clock Time	Port/Point ID	Sample Time (min.)	DGM Reading (DACF)	ΔP (in H_2O)	ΔH (in H_2O)	Stack Temp (F)	Probe Temp (°F)	Filter Temp (°F)	Imp. Outlet Temp (°F)	Filter Temp Exit (°F)	DGM Temp (°F)		Vacuum (in Hg)
1324	A/1	0	337.90	3.2	1.0	642	N/A	N/A	60	N/A	84	83	3.5
	2	10		4.05	1.0	645			48		86	82	3.5
	3	20	349.36	4.0	1.0	630			48		86	83	3.5
	4	30	355.03	3.2	1.0	615			48		86	83	3.5
	B/1	40	360.67	3.40	1.0	644			49		87	83	3.5
	2	50	366.73	4.25	1.0	647			48		87	81	3.5
1424	3	60	372.11	3.40	—	645	—	—		—	—	—	—
	4			3.20		641							

Total Time	Vol. (DACF)	Avg. $\sqrt{\Delta P}$	Avg. ΔH	Avg. t_s	Average DGM Temp	Max. Vac.
60	34.00	1.92	1.0	636	85.1	3.5

QC Check (Printout Only) _____

Field Team Leader Review (Original Only) _____

10/16/04

Isokinetic Workbook-CIRC.xls: RM 5 RUN 1

APPENDIX B
CALIBRATION AND FIELD NOTES

Emissions Measurements Report
McMinnville Electric System
200 West Morford Street
McMinnville, Tennessee
17OT.98726.00
December 2006

Scott Specialty Gases

Shipped 500 WEAVER PARK RD
From: LONGMONT CO 80501
Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ANALYSIS

SECOR

318 SEABOARD LANE
SUITE 101
FRANKLIN TN 37067

PROJECT #: 08-33467-007
PO#: 1706-1017
ITEM #: 0801811 AL
DATE: 23Feb2006

CYLINDER #: ALM022668
FILL PRESSURE: 2000 PSIG

PURE MATERIAL: NITROGEN CAS# 7727-37-9

GRADE: U Z A M

PURITY: 99.999%

IMPURITY	MAXIMUM CONCENTRATIONS	ACTUAL CONCENTRATIONS
THC	0.05 PPM	< 0.05 PPM
CO	0.10 PPM	< 0.10 PPM
O2	2 PPM	< 2 PPM
CO2	1 PPM	< 1 PPM
NOX	0.02 PPM	< 0.02 PPM
SF6	0.001 PPM	< 0.001 PPM
SO2	0.005 PPM	< 0.005 PPM
H2O	4 PPM	< 4 PPM

CGA 580

ANALYST: _____
WAYNE JOHNSON

Scott Specialty Gases

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500 WEAVER PARK RD,LONGMONT,CO 80501 Phone: 888-253-1635 Fax: 303-772-7673

Dual-Analyzed Calibration Standard

CERTIFICATE OF ACCURACY: Interference Free™ Multi-Component EPA Protocol Gas

Assay Laboratory
SCOTT SPECIALTY GASES
500 WEAVER PARK RD
LONGMONT,CO 80501

P.O. No.: 1706-1017
Project No.: 08 -33467 -008

Customer
SECOR

318 SEABOARD LANE
SUITE 101
FRANKLIN TN 37067

ANALYTICAL INFORMATION

This certification was performed according to EPA Traceability Protocol For Assay & Certification of Gaseous Calibration Standards, Procedure G-1; September, 1997.

Cylinder Number: ALM009913 **Certification Date:** 21Feb2006 **Exp. Date:** 20Feb2009
Cylinder Pressure*:** 2000 PSIG

COMPONENT	CERTIFIED CONCENTRATION (Moles)	ANALYTICAL ACCURACY**	TRACEABILITY
CARBON DIOXIDE	12.4 %	+/- 1%	Direct NIST and
OXYGEN	12.5 %	+/- 1%	Direct NIST and
NITROGEN	BALANCE		

*** Do not use when cylinder pressure is below 150 psig.
** Analytical accuracy is based on the requirements of EPA Protocol Procedure G1, September 1997.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPC
NTRM 1800	04Jul2008	K010492	17.87 %	CARBON
NTRM 2658	02Oct2006	ALM065037	9.930 %	OXYGEN

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
FTIR//000929062	21Feb2006	FTIR
HPGC/5890/3115A34624	14Feb2006	TCD

ANALYZER READINGS

(Z=Zero Gas R=Reference Gas T=Test Gas r=Correlation Coefficient)

First Triad Analysis
CARBON DIOXIDE
Date: 21Feb2006 Response Unit: %
Z1=0.00025 R1=17.85852 T1=12.42262
R2=17.87372 Z2=0.00743 T2=12.42652
Z3=0.00855 T3=12.42953 R3=17.87888
Avg. Concentration: 12.42 %
OXYGEN
Date: 17Feb2006 Response Unit: %
Z1=0.00000 R1=210161.0 T1=264469.0
R2=211578.0 Z2=0.00000 T2=264564.0
Z3=0.00000 T3=264933.0 R3=211521.0
Avg. Concentration: 12.54 %

Second Triad Analysis

Calibration Curve

Concentration=A+Bx+Cx2+Dx3+Ex4
r=9.99981E-1
Constants: A=0.00000E+0
B=9.12314E-1 C=1.22200E-2
D=0.00000E+0 E=0.00000E+0

Concentration=A+Bx+Cx2+Dx3+Ex4
r=0.999999
Constants: A=-0.00289913
B=4.68E-05 C=2.88E-12
D= E=

Special Notes:
RANGE 12-13% O2 & CO2

Scott Specialty Gases

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500 WEAVER PARK RD,LONGMONT,CO 80501 Phone: 888-253-1635 Fax: 303-772-7673

Dual-Analyzed Calibration Standard

CERTIFICATE OF ACCURACY: Interference Free™ Multi-Component EPA Protocol Gas

Assay Laboratory
SCOTT SPECIALTY GASES
500 WEAVER PARK RD
LONGMONT,CO 80501

P.O. No.: 1706-1017
Project No.: 08 -33467 -009

Customer
SECOR
318 SEABOARD LANE
SUITE 101
FRANKLIN TN 37067

ANALYTICAL INFORMATION

This certification was performed according to EPA Traceability Protocol For Assay & Certification of Gaseous Calibration Standards, Procedure G-1; September, 1997.

Cylinder Number: ALM008258 **Certification Date:** 21Feb2006 **Exp. Date:** 20Feb2009
Cylinder Pressure*:** 2000 PSIG

COMPONENT	CERTIFIED CONCENTRATION (Moles)	ANALYTICAL ACCURACY**	TRACEABILITY
CARBON DIOXIDE	19.7 %	+/- 1%	Direct NIST and
OXYGEN	20.0 %	+/- 1%	Direct NIST and
NITROGEN	BALANCE		

*** Do not use when cylinder pressure is below 150 psig.
** Analytical accuracy is based on the requirements of EPA Protocol Procedure G1, September 1997.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPO
NTRM 1800	04Jul2008	K010492	17.87 %	CARBON
NTRM 2658	02Oct2006	ALM065037	9.930 %	OXYGEN

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
FTIR//000929062	21Feb2006	FTIR
HPGC/5890/3115A34824	14Feb2006	TCD

ANALYZER READINGS

(Z=Zero Gas R=Reference Gas T=Test Gas r=Correlation Coefficient)

First Triad Analysis
CARBON DIOXIDE
Date: 21Feb2006 Response Unit: %
Z1=0.00025 R1=17.85852 T1=19.67862
R2=17.87372 Z2=0.00743 T2=19.68294
Z3=0.00855 T3=19.69446 R3=17.87888
Avg. Concentration: 19.69 %
OXYGEN
Date: 17Feb2006 Response Unit: %
Z1=0.00000 R1=210161.0 T1=418358.0
R2=211578.0 Z2=0.00000 T2=418397.0
Z3=0.00000 T3=418406.0 R3=211521.0
Avg. Concentration: 20.01 %

Second Triad Analysis

Calibration Curve

Concentration=A+Bx+Cx2+Dx3+Ex4
r=9.99981E-1
Constants: A=0.00000E+0
B=9.12314E-1 C=1.22200E-2
D=0.00000E+0 E=0.00000E+0

Concentration=A+Bx+Cx2+Dx3+Ex4
r=0.999999
Constants: A=-0.00289913
B=4.68E-05 C=2.88E-12
D= E=

QUALITY ASSURANCE

Airgas

Airgas Specialty Gases
12722 S. Wentworth Avenue
Chicago, IL 60628
1-733-785-3000
Fax: 1-733-785-1928

Certificate of Analysis

Date of Analysis:	6/26/2006	Reference Number:	54-124068484-3
Customer Name:		Part Number:	X03NI99C15A4554
Grade of Product:	CERTIFIED STANDARD-SPEC		

Cylinder Number	Component	Requested Concentration	Actual Concentration
CC111673	NITROGEN DIOXIDE	50 PPM	52.29 PPM
	OXYGEN	1000 PPM	860 PPM
	NITROGEN	Balance	Balance

Notes:

Relative Uncertainty of Analytical Value: +/- 2% of component or +/- 5% of component, if less than 50 PPM
Product composition verified by direct comparison to calibration standards traceable to NIST weights and/or NIST gas mixture reference materials

Approval Signature _____

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RATA CLASS

Dual-Analyzed Calibration Standard

Scott Specialty Gases

500 WEAVER PARK RD.LONGMONT,CO 80501 Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ACCURACY: Interference Free™ Multi-Component EPA Protocol Gas

Assay Laboratory

SCOTT SPECIALTY GASES
500 WEAVER PARK RD
LONGMONT,CO 80501

P.O. No.: 012-1518
Project No.: 08-28183-001

Customer
SECOR

318 SEABOARD LANE
SUITE 101
FRANKLIN TN 37067

ANALYTICAL INFORMATION

This certification was performed according to EPA Traceability Protocol For Assay & Certification of Gaseous Calibration Standards; Procedure G-1; September, 1997.

Cylinder Number: ALM035625 **Certification Date:** 19Sep2005 **Exp. Date:** 19Sep2007
Cylinder Pressure*:** 1940 PSIG

COMPONENT	CERTIFIED CONCENTRATION (Moles)		ACCURACY**	TRACEABILITY
CARBON MONOXIDE	45.7	PPM	+/- 1%	Direct NIST and NMi
NITRIC OXIDE	44.1	PPM	+/- 1%	Direct NIST and NMi
NITROGEN - OXYGEN FREE		BALANCE		
TOTAL OXIDES OF NITROGEN	44.2	PPM		Reference Value Only

*** Do not use when cylinder pressure is below 150 psig.
** Analytical accuracy is based on the requirements of EPA Protocol Procedure G1, September 1997.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
NTRM 1678	02Oct2008	ALM047202	50.53 PPM	CARBON MONOXIDE
NTRM 1683	01Nov2006	AAL069884	48.80 PPM	NITRIC OXIDE

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
FTIR//000929062	13Sep2005	FTIR
FTIR//000929062	02Sep2005	FTIR

ANALYZER READINGS

(Z = Zero Gas R = Reference Gas T = Test Gas r = Correlation Coefficient)

First Triad Analysis | **Second Triad Analysis** | **Calibration Curve**

CARBON MONOXIDE

Date: 12Sep2005 Response Unit:PPM
Z1 = 0.00948 R1 = 50.46907 T1 = 45.55918
R2 = 50.48410 Z2 = 0.01230 T2 = 45.58730
Z3 = 0.02806 T3 = 45.62582 R3 = 50.51853
Avg. Concentration: 45.62 PPM

Date: 19Sep2005 Response Unit: PPM
Z1 = -0.03004 R1 = 50.40138 T1 = 45.64965
R2 = 50.44690 Z2 = 0.00790 T2 = 45.65846
Z3 = 0.01721 T3 = 45.70020 R3 = 50.46435
Avg. Concentration: 45.75 PPM

Concentration = A + Bx + Cx2 + Dx3 + Ex4
r = 9.99996E-1
Constants: A = 0.00000E+0
B = 8.23042E-1 C = 4.91000E-4
D = 1.00000E-6 E = 0.00000E+0

NITRIC OXIDE

Date: 12Sep2005 Response Unit:PPM
Z1 = -0.05063 R1 = 49.01477 T1 = 44.09956
R2 = 49.02575 Z2 = -0.01565 T2 = 44.11199
Z3 = 0.01102 T3 = 44.25096 R3 = 49.15103
Avg. Concentration: 43.92 PPM

Date: 19Sep2005 Response Unit: PPM
Z1 = -0.07630 R1 = 48.84497 T1 = 44.24450
R2 = 48.86665 Z2 = -0.04403 T2 = 44.35786
Z3 = 0.05034 T3 = 44.37558 R3 = 48.89694
Avg. Concentration: 44.27 PPM

Concentration = A + Bx + Cx2 + Dx3 + Ex4
r = 9.99997E-1
Constants: A = 0.00000E+0
B = 9.99261E-1 C = 2.02000E-4
D = 0.00000E+0 E = 0.00000E+0

APPROVED BY: Jon Witzak

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RATA CLASS

Dual-Analyzed Calibration Standard

Scott Specialty Gases

500 WEAVER PARK RD,LONGMONT,CO 80501 Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ACCURACY: Interference Free™ Multi-Component EPA Protocol Gas

Assay Laboratory

SCOTT SPECIALTY GASES
500 WEAVER PARK RD
LONGMONT,CO 80501

P.O. No.: 012-1518
Project No.: 08-28183-002

Customer
SECOR

318 SEABOARD LANE
SUITE 101
FRANKLIN TN 37067

ANALYTICAL INFORMATION

This certification was performed according to EPA Traceability Protocol For Assay & Certification of Gaseous Calibration Standards; Procedure G-1; September, 1997.

Cylinder Number: ALM052581 **Certification Date:** 19Sep2005 **Exp. Date:** 19Sep2007
Cylinder Pressure*:** 1950 PSIG

COMPONENT	CERTIFIED CONCENTRATION (Moles)		ACCURACY**	TRACEABILITY
CARBON MONOXIDE	90.1	PPM	+/- 1%	Direct NIST and NMi
NITRIC OXIDE	89.6	PPM	+/- 1%	Direct NIST and NMi
NITROGEN - OXYGEN FREE		BALANCE		
TOTAL OXIDES OF NITROGEN	89.7	PPM		Reference Value Only

*** Do not use when cylinder pressure is below 150 psig.
** Analytical accuracy is based on the requirements of EPA Protocol Procedure G1, September 1997.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
NTRM 1679	02Apr2007	ALM064795	94.90 PPM	CARBON MONOXIDE
NTRM 1684	04Jul2008	AAL070281	97.00 PPM	NITRIC OXIDE

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
FTIR//000929062	13Sep2005	FTIR
FTIR//000929062	02Sep2005	FTIR

ANALYZER READINGS

(Z = Zero Gas R = Reference Gas T = Test Gas r = Correlation Coefficient)

First Triad Analysis	Second Triad Analysis	Calibration Curve
CARBON MONOXIDE		
Date: 12Sep2005 Response Unit:PPM	Date: 19Sep2005 Response Unit: PPM	Concentration = A + Bx + Cx2 + Dx3 + Ex4
Z1 = -0.00878 R1 = 94.69398 T1 = 90.18430	Z1 = -0.00046 R1 = 94.93542 T1 = 89.88282	r = 9.99996E-1
R2 = 94.75741 Z2 = 0.01697 T2 = 90.19540	R2 = 94.93751 Z2 = 0.01543 T2 = 89.91845	Constants: A = 0.00000E+0
Z3 = 0.02023 T3 = 90.29296 R3 = 94.81706	Z3 = 0.03510 T3 = 89.95514 R3 = 94.99243	B = 5.00827E-1 C = 1.81G00E-4
Avg. Concentration: 90.36 PPM	Avg. Concentration: 89.87 PPM	D = 0.00000E+0 E = 0.00000E+0
NITRIC OXIDE		
Date: 12Sep2005 Response Unit:PPM	Date: 19Sep2005 Response Unit: PPM	Concentration = A + Bx + Cx2 + Dx3 + Ex4
Z1 = -0.03258 R1 = 96.18385 T1 = 89.04660	Z1 = 0.00577 R1 = 96.60609 T1 = 88.75561	r = 9.99997E-1
R2 = 96.28058 Z2 = 0.01744 T2 = 89.14977	R2 = 96.62463 Z2 = 0.07686 T2 = 89.07843	Constants: A = 0.00000E+0
Z3 = 0.06295 T3 = 89.15435 R3 = 96.35553	Z3 = 0.11514 T3 = 89.09835 R3 = 96.64430	B = 9.99261E-1 C = 2.02000E-4
Avg. Concentration: 89.79 PPM	Avg. Concentration: 89.32 PPM	D = 0.00000E+0 E = 0.00000E+0

APPROVED BY: Jon Witzak

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Airgas

Airgas Specialty Gases
12722 S. Wentworth Avenue
Chicago, IL 60628
1-773-785-3000
Fax: 1-773-785-1928
http://www.airgas.com

Certificate of Analysis: EPA Protocol Gas Mixture

Cylinder Number: XC028782B Reference Number: 54-124074291-1
Cylinder Pressure: 2000.6 PSIG Expiration Date: 9/12/2008
Certification Date: 9/12/2006 Laboratory: ASG - Chicago - IL

Certified Concentrations

Component	Concentration	Accuracy	Analytical Principle	Procedure
CARBON MONOXIDE	499.9 PPM	+/- 1%	FTIR	G1
NITRIC OXIDE	500.8 PPM	+/- 1%	FTIR	G1
SULFUR DIOXIDE	518.7 PPM	+/- 1%	FTIR	G1
NITROGEN	Balance			
Total oxides of nitrogen	501.2 PPM			

Certification performed in accordance with "EPA Traceability Protocol (Sept. 1997)" using the assay procedures listed. Analytical Methodology does not require correction for analytical interferences.

Notes:

Do not use cylinder below 150 psig. Approval Signature _____

Reference Standard Information

Type	Balance Gas	Component	Cyl.Number	Concentration
NTRM 1051108		SULFUR DIOXIDE	SG9149767BAL	1251 PPM
NTRM 111203		NITRIC OXIDE	SG9134620BAL	990.6 PPM
NTRM 52403		CARBON MONOXIDE	SG9162928BAL	973.6 PPM

Analytical Results

1st Component CARBON MONOXIDE

1st Analysis Date: 09/05/2006

R 985.2	S 506.2	Z 1.090	Conc 499.7 PPM
S 507.3	Z 1.085	R 988.3	Conc 499.3 PPM
Z 1.073	R 985.7	S 506.9	Conc 500.1 PPM
			AVG: 499.7 PPM

2nd Analysis Date: 09/12/2006

R 980.9	S 506.1	Z 1.09	Conc 501.8 PPM
S 505.2	Z 1.07	R 983.5	Conc 499.5 PPM
Z 1.09	R 986.8	S 506.7	Conc 499.4 PPM
			AVG: 500.2 PPM

2nd Component NITRIC OXIDE

1st Analysis Date: 09/05/2006

R 997.6	S 504.7	Z 3.508	Conc 499.4 PPM
S 506.1	Z 3.637	R 996.1	Conc 501.5 PPM
Z 3.629	R 995.1	S 505.6	Conc 501.5 PPM
			AVG: 500.8 PPM

2nd Analysis Date: 09/12/2006

R 994.6	S 505.5	Z 4.17	Conc 501.4 PPM
S 506.1	Z 3.99	R 997.1	Conc 500.8 PPM
Z 3.87	R 996.8	S 505.7	Conc 500.6 PPM
			AVG: 500.9 PPM

3rd Component SULFUR DIOXIDE

1st Analysis Date: 09/05/2006

R 1262	S 523.2	Z -0.180	Conc 518.6 PPM
S 522.5	Z -0.262	R 1261	Conc 518.6 PPM
Z 0.081	R 1261	S 523.4	Conc 519.4 PPM
			AVG: 518.8 PPM

2nd Analysis Date: 09/12/2006

R 1259	S 521.7	Z -0.41	Conc 518.8 PPM
S 520.8	Z -0.04	R 1257	Conc 518.3 PPM
Z -0.29	R 1257	S 521.1	Conc 518.9 PPM
			AVG: 518.6 PPM

Airgas

Airgas Specialty Gases
12722 S. Wentworth Avenue
Chicago, IL 60628
1-773-785-3000
Fax: 1-773-785-1928
http://www.airgas.com

Certificate of Analysis: EPA Protocol Gas Mixture

Cylinder Number: SG9133859BAL
Cylinder Pressure: 2000.6 PSIG
Certification Date: 9/21/2006
Reference Number: 54-124074173-1A
Expiration Date: 9/21/2008
Laboratory: ASG - Chicago - IL

Certified Concentrations

Component	Concentration	Accuracy	Analytical Principle	Procedure
NITRIC OXIDE	988.64 PPM	+/- 1%	FTIR	G1
CARBON MONOXIDE	999.57 PPM	+/- 1%	FTIR	G1
SULFUR DIOXIDE	1039.00 PPM	+/- 1%	FTIR	G1
NITROGEN	Balance			

Total oxides of nitrogen 994.0 PPM

Certification performed in accordance with "EPA Traceability Protocol (Sept. 1997)" using the assay procedures listed. Analytical Methodology does not require correction for analytical interferences.

Notes:

Do not use cylinder below 150 psig.

Approval Signature

Reference Standard Information

Type	Balance Gas	Component	Cyl.Number	Concentration
NTRM 1051108		SULFUR DIOXIDE	SG9149767BAL	1251 PPM
NTRM 100703		NITRIC OXIDE	SG9169554BAL	1477 PPM
NTRM 20503		CARBON MONOXIDE	SG9153846BAL	2484 PPM

Analytical Results

1st Component NITRIC OXIDE

1st Analysis Date: 09/13/2006

R 1507	S 1006	Z -1.17	Conc 986.2 PPM
S 1003	Z -1.10	R 1499	Conc 989.2 PPM
Z -0.96	R 1501	S 999.6	Conc 984.0 PPM
			AVG: 986.4 PPM

2nd Analysis Date: 09/21/2006

R 1498.5	S 1003.7	Z -.716	Conc 989.51 PPM
S 1004.4	Z -.690	R 1492.9	Conc 993.86 PPM
Z -.995	R 1491.5	S 998.47	Conc 989.09 PPM
			AVG: 990.82 PPM

2nd Component CARBON MONOXIDE

1st Analysis Date: 09/13/2006

R 2562	S 1027	Z 4.49	Conc 993.2 PPM
S 1028	Z 4.51	R 2557	Conc 996.4 PPM
Z 4.50	R 2536	S 1025	Conc 1002 PPM
			AVG: 997.20 PPM

2nd Analysis Date: 09/21/2006

R 2539.4	S 1023.2	Z 4.40	Conc 998.29 PPM
S 1015.4	Z 4.42	R 2517.4	Conc 999.33 PPM
Z 4.41	R 2503.4	S 1018.7	Conc 1008.2 PPM
			AVG: 1001.94 PPM

3rd Component SULFUR DIOXIDE

1st Analysis Date: 09/13/2006

R 1262	S 1049	Z -0.71	Conc 1040 PPM
S 1050	Z 0.12	R 1263	Conc 1041 PPM
Z 0.22	R 1262	S 1050	Conc 1040 PPM
			AVG: 1040 PPM

2nd Analysis Date: 09/21/2006

R 1265.5	S 1050.2	Z -.258	Conc 1038.2 PPM
S 1048.6	Z -.194	R 1264.7	Conc 1037.2 PPM
Z .318	R 1264.0	S 1048.5	Conc 1037.6 PPM
			AVG: 1037.6 PPM

ALTERNATIVE METHOD 2
THERMOCOUPLE CALIBRATION PROCEDURE

INTRODUCTION

In EPA Method 2, EPA recommended the use of an extrapolation technique for a simplified, post-test, thermocouple calibration procedure using a two point calibration: (1) ice bath and (2) boiling water. Because of the inherent accuracy and precision of the thermocouple within ±1.3°F in the range of -32°F to 2500°F, the two-point post-test calibration procedure may be replaced with a single-point check.

A single-point calibration procedure that checks the operation of a thermocouple system within ±1.0 percent of the absolute measured temperature is all that is necessary to check the system for the presence of disconnected wire junctions, other loose connections, or a potential miscalibrated emf readout. A system that performs accurately at one temperature is expected to behave similarly at other temperatures.

Therefore, an alternative to the Method 2, two-point, thermocouple calibration can be used and the procedure is as follows:

ALTERNATIVE POST-TEST AND RECOMMENDED PRETEST CALIBRATION PROCEDURE

After each test run series, check the accuracy (and, hence, the calibration) of each thermocouple system at ambient temperature, or any other temperature, within the range specified by the manufacture, using a reference thermometer (either ASTM reference thermometer or a thermometer that has been calibrated against an ASTM reference thermometer). The temperatures of the thermocouple and reference thermometers shall agree to within ±2°F.

A crimp in the connecting wires or crossed lines that change the location of the reference junction will affect readings. Check the continuity of the thermocouple by subjecting it to a change in the temperature (e.g.., removing it from the stack or touching an ice cube). This step will also check for loose connections and reversed connections (noted by a wrong change in the temperature).

To ensure linearity of the measurements, it is recommended that the emf meter be originally calibrated against a NIST traceable or a comparable voltage source at several points covering the range of intended use, e.g., 0, 500, 1000, and 2000°F.

REFERENCE

1. Shigehara, R.T., E.W. Stewart, Kenneth Alexander, "Simplified Thermocouple Calibration Procedure", Entropy, Incorporated, contained in the EMTIC TSAR Library.

DRY GAS METER POST-TEST CALIBRATION CHECK

Client: McMinnville Electric | Location: McMinnville, TN

Source: Engine Exhaust | Date: November 28, 2006

Meter Box I.D. 1.00 | Full Range Cal. Date:

Calibrated Y: 0.9554 | $\Delta H_{@}$: 1.9937

Run 1		Run 2		Run 3		Run 4	
ΔH	SQRT ΔH	ΔH	SQRT ΔH	ΔH	SQRT ΔH	ΔH	SQRT ΔH
1.00	1.00	1.00	1.00	1.00	1.00		
1.00	1.00	1.00	1.00	1.00	1.00		
1.00	1.00	1.00	1.00	1.00	1.00		
1.00	1.00	1.00	1.00	1.00	1.00		
1.00	1.00	1.00	1.00	1.00	1.00		
1.00	1.00	1.00	1.00	1.00	1.00		

$[SQRT\Delta H]_{avg}$ =	1.00	$[SQRT\Delta H]_{avg}$ =	1.00	$[SQRT\Delta H]_{avg}$ =	1.00	$[SQRT\Delta H]_{avg}$ =	
$[\Delta H]_{avg}$ =	1.00	$[\Delta H]_{avg}$ =	1.00	$[\Delta H]_{avg}$ =	1.00	$[\Delta H]_{avg}$ =	
M_d (lb/lb-mol) =	29.60	M_d (lb/lb-mol) =	29.60	M_d (lb/lb-mol) =	29.60	M_d (lb/lb-mol) =	
P_b (in. Hg) =	29.1	P_b (in. Hg) =	29.1	P_b (in. Hg) =	29.05	P_b (in. Hg) =	
T_m (°R) =	538	T_m (°R) =	544	T_m (°R) =	544	T_m (°R) =	
V_m (ft^3) =	34.185	V_m (ft^3) =	30.665	V_m (ft^3) =	34.1	V_m (ft^3) =	
θ (min) =	60	θ (min) =	60	θ (min) =	60	θ (min) =	
Y_{qa} =	0.9432	Y_{qa} =	1.0583	Y_{qa} =	0.9525	Y_{qa} =	

Average Y_{qa} = 0.9846

% difference = 3.06 Pass

11-30-06

Eng_Exh_RM4.xls: Postcal

SECOR
Dry Gas Meter (DGM) Calibration

DGM Serial No.: 1197480
DGM ID: 1

Standard Serial No.: 593564
Standard Y_d: 1.009

P_{bar}: 29.40
Date: 01-May-06

Standard				Dry Gas Meter									
								Temperature (°F)					
Initial Volume (ft^3)	Final Volume (ft^3)	Total Volume (ft^3)	Temperature (°F)	ΔH ($in.H_2O$)	Initial Volume (ft^3)	Final Volume (ft^3)	Total Volume (ft^3)	Inlet	Outlet	Average	Time (min.)	DGM Coefficient (Y_d)	$\Delta H_@$ ($in.H_2O$)
702.230	706.200	4.006	89	0.5	620.180	624.150	3.970	71	70	71	10.0	0.9738	1.9089
706.200	710.100	3.935	89	0.5	624.150	628.150	4.000	71	70	71	10.0	0.9494	1.9780
710.100	714.050	3.986	89	0.5	628.150	632.150	4.000	76	75	76	10.0	0.9707	1.9103
714.050	719.000	4.995	89	1.0	632.150	637.150	5.000	77	76	77	9.0	0.9737	1.9669
719.000	723.850	4.894	89	1.0	637.150	642.200	5.050	77	76	77	9.0	0.9446	2.0488
723.850	728.750	4.944	89	1.0	642.200	647.250	5.050	75	74	75	9.0	0.9508	2.0147
728.750	734.100	5.398	89	1.5	647.250	652.700	5.450	77	76	77	8.0	0.9643	1.9956
734.100	739.350	5.297	89	1.5	652.700	658.200	5.500	78	77	78	8.0	0.9394	2.0685
739.350	744.750	5.449	89	1.5	658.200	663.750	5.550	80	79	80	8.0	0.9611	1.9479
744.750	750.250	5.550	90	2.0	663.750	669.400	5.650	81	80	81	7.0	0.9604	1.9203
750.250	755.600	5.398	89	2.0	669.400	675.000	5.600	81	80	81	7.0	0.9443	2.0221
755.600	761.050	5.499	90	2.0	675.000	680.600	5.600	82	81	82	7.0	0.9620	1.9520
761.050	766.600	5.600	90	3.0	680.600	686.400	5.800	82	81	82	6.0	0.9435	2.0744
766.600	772.200	5.650	90	3.0	686.400	692.200	5.800	83	82	83	6.0	0.9538	2.0338
772.200	777.760	5.610	90	3.0	692.200	698.050	5.850	83	82	83	6.0	0.9389	2.0631
											Average	**0.9554**	**1.9937**

THERMOCOUPLE CALIBRATION

Standard ID: Traceable #1 Standard Serial No.: 349920

Inlet (°F)			Outlet (°F)	
Standard	DGM	Difference	DGM	Difference
672	664	1.19	664	1.19
493.5	491	0.51	494	0.10
671.1	668	0.46	667	0.61
494.2	489	1.05	490	0.85
670.6	668	0.39	666	0.69
493.7	490	0.75	493	0.14

ALTERNATIVE METHOD 5 POST-TEST CALIBRATION

INTRODUCTION AND BACKGROUND

EPA Method 5 requires the calibration of the metering system after each field use. Because the post-test calibration requires the use of a spirometer or wet test meter, the calibration is often conducted in the laboratory. However, a field calibration procedure is highly desirable for two reasons: (1) it eliminates questions about the possibility of the damage to the metering system occurring during transport and (2) it eliminates travel costs for a retest if the metering system fails the post-test calibration.

The alternative post-test calibration procedure described below is based on the principles of the optional pretest orifice meter coefficient check in Section 4.4.1 of Method 5. Since the orifice meter coefficient check will not detect leakages between the inlet of the metering system and the dry gas meter, the alternative procedure includes two additional steps: (1) a leak check from either the inlet of the sampling train or the inlet of the metering system and (2) a leak check of that portion of the sampling train from the pump to the orifice meter.

PROCEDURE

The alternative to the post-test calibration in Section 5.3.2 of Method 5 is as follows:

After each test run, do the following:

1. Ensure that the metering system has passed the post-test leak-check. If not, conduct a leak-check of the metering system from its inlet.

2. Conduct the leak-check of that portion of the train from the pump to the orifice meter as described in Section 5.6 of Method 5.

3. Calculate Y_{qa} for each test run using the following equation:

$$Y_{qa} = \frac{\bullet}{V_m}\sqrt{\frac{0.0319 T_m}{\bullet H_@ \left(P_b + \bullet \frac{H_{avg}}{13.6}\right)} \frac{29}{M_d}}\ (\sqrt{\bullet H})_{avg}$$

where:

Y_{qa} = dry gas meter calibration check value, dimensionless.
• = total run time, min.
V_m = total sample volume measured by dry gas meter, dcf.
T_m = absolute average dry gas meter temp., °R.
P_b = barometric pressure, in. Hg.
0.0319 = $(29.92/528)(0.75)^2$ (in. Hg/°/R) cfm^2.
$•h_{avg}$ = average orifice meter differential, in. H_2O.
•H@ = orifice meter calibration coefficient, in. H_2O.
M_d = dry molecular weight of stack gas, lb/lb-mole.
29 = dry molecular weight of air, lb/lb-mole.
13.6 = specific gravity of mercury.

After each test run series, do the following:

4. Average the three or more Y_{qa}'s obtained from the test run series and compare this average Y_{qa} with the dry gas meter calibration factor, Y. The average Y_{qa} must be within 5 percent of Y.

5. If the average Y_{qa} does not meet the ±5 percent criterion, recalibrate the meter over the full range of orifice settings, as detailed in Section 5.3.1 of Method 5. Then follow the procedure in Section 5.3.3 of Method 5.

REFERENCE

1. Roger T. Shigehara, P.G. Royals, and E.W. Steward, "Alternative Method 5 Post-Test Calibration", Entropy, Inc, contained in the EMTIC TSAR Library.

1630 - off site

1730 - drive to Murfreesboro & meet Mullins w/ chamber pump

2 hr. trip to stpmt

2115 - @ hotel - NOx monitor on in trailer

11/28/06

0700 - @ - site

0730 - begin inst calb

- NO_x on 0-100 range for conv. eff ck.

0758 - NO_x conv. eff. ck. - 52.29 NO_2 in N_2

N_2 - ALM022668 ✓ bl/ut - 1,000

O_2/CO_2 - 20.0/19.7 - ALM008258 - bl/rd. - 2,600

- 12.5/12.4 - ALM004913 - bl/yl - 1,900

NO_x - 896 - ALM052581 - bk/bk - 1,200 psi

- 444.1 - ALM035625 - bk/rd - 500 psi

NO_2 - 5.29 - CC111673 ✓

0806 - bias ck. sys.

NO_x resp. time	down	up
cL (scc)	114	121

NO_x - 988.6 - SG9133859 BAL - bk/LL - 1,700

- 500.8 - XC025782B - bk/rd - 1,600

0900 - on-line @ engine exhaust

- ≈ 650 ppm

- re-cal NO_x on 0-1,000 range

0915 - NO_x re-cal

0927 - NO_x bias

0936 - on-line

- NO_x running ≈ 750 ppm

0948 - NO_x strm cl. panel A pt. 1

0952 - panel A pt. 2

0954 - 4/5

S13-E134

11/28/00

0950 - A/4
0957 - ~~not~~ switch ports
1001 - port B/pt. 1
1003 - B/2
1005 - B/3
1007 - B/4
1027 - start R-1
1127 - end R-1, bias/drift ck.
1154 - start R-2
1254 - end R-2. bias/drift ck.
1323 - start R-3
1423 - end R-3. bias/drift ck. post test calb
1530 - depart site
1715 - @ office
- talk w/ Ed @ Horizon re: Vertis - Pomona
- results in > 99.9% DE
- coating sample analysis ?
- BOC - sed, cool, proposal, ~~TPI~~
- Bakery Foods - Albertville, AL
- MSGP (11/27)
- M. Schmidt - faxing acceptance of proposal for Albertville
- Russellville, KY - PM on boiler
- Chris - Vertis - Columbus - 11/28

~~0744 2744~~

1730 - to office

11/29/00

0800 - @ office

APPENDIX C
PRODUCTION DATA

Emissions Measurements Report
McMinnville Electric System
200 West Morford Street
McMinnville, Tennessee
17OT.98726.00
December 2006

Device ID: 89498523
Serial Number: 89498523
Kh: 1.8

Interval Length: 30 min

Values are in units

Date	Time	Pulse	Meter Voltage	kWh	Generator Voltage
11/28/2006	9:30:00	0.5995	122.33	827.31	489.31
11/28/2006	10:00:00	0.5994	122.40	827.17	489.60
11/28/2006	10:30:00	0.5989	122.46	826.48	489.83
11/28/2006	11:00:00	0.5992	122.71	826.90	490.84
11/28/2006	11:30:00	0.5995	122.85	827.31	491.40
11/28/2006	12:00:00	0.5991	123.04	826.76	492.15
11/28/2006	12:30:00	0.5992	123.01	826.90	492.05
11/28/2006	13:00:00	0.5992	123.04	826.90	492.18
11/28/2006	13:30:00	0.5991	123.02	826.76	492.08
11/28/2006	14:00:00	0.5989	123.21	826.48	492.83
11/28/2006	14:30:00	0.5988	123.45	826.34	493.80
				1,652.8 kWh	

Run 1 = 826.90 kWh + 827.31 kWh = 1,654.2 kWh

Run 2 = 826.90 + 826.90 = 1,653.8 kWh

Attachment "G"

(The following report, which pertains solely to emissions measurement testing and fuel quality was submitted by Ralph Boroughs on behalf of the Tennessee Valley Authority as part of this Project and is therefore incorporated and made part of this Final Report as submitted.)

TVA Activities in Support of the McMinnville BioDiesel / SCONOX Project

Introduction

TVA's interest in this project stemmed from a desire to develop clean, renewable generation, and to be responsive to customer proposals; in this case, a proposal from McMinnville Electric System (MES) to install a new generator, dedicated to biodiesel fuel, and equipped with an advanced NOx removal system.

As a 'power production' project, TVA was not interested in any new diesel generation, primarily because of the high NOx emissions of diesels. Biodiesel, while cleaner burning in many respects, has not been shown to reduce NOx, and in some cases even increase NOx emissions. (TVA's policy "not to pursue or consider new contracts for use or installation of additional diesel generation", was established February 22, 2001, and was re-affirmed in July 2002 after reviewing the MES proposal.) Nevertheless, TVA did approve our participation in a 'research and development' project to test advanced emissions controls, using biodiesel in a diesel-generator set.

The TVA role in the overall project was focused on primarily on emission monitoring, to verify that the NOx removal system could meet TVA emissions targets. A target NOx limit was set at 0.16 pounds per million BTU, 1.57 pounds per MWh, or 0.5 grams per brake horsepower-hour, based on TVA's internal environmental review in 2002. This limit corresponds to emissions achievable by a well-controlled coal-fired plant, but is much stricter than any then-existing emissions standards for diesels. TVA's NOx target has no direct linkage to EPA or Tennessee regulations for diesels, but is instead a goal, which, if met, might motivate and inform a reconsideration of TVA's policy on diesel generation.

[TVA did not participate in emissions testing for compliance with state air permits, because state-approved testing of diesels requires specialized equipment as well as detailed knowledge of state regulations and how they are applied.]

Although TVA was primarily focused on emissions monitoring, TVA also contributed to the project planning process and fuel testing.

Test Plan

The actual testing schedule did not follow the planned schedule. Phases 1 through 3 were compressed to compensate for time and cost overruns earlier in the project. Phase 4 was compressed further, because problems with the plasma reformer (which we had hoped to resolve in phase 1) kept recurring, and attempts to resolve these problems added additional costs. The table below compares an early test plan to the actual implementation.

Test Phase	Description	Planned Duration	Actual Duration
1	Commissioning, Start up, & Regeneration System Tests	10 days	~4.5 days 6/29-7/3
2	Initial Reactor Testing & Characterization	5 days	~1.5 days 7/3-7/5
3	Fuel Blend Tests, ULSO, B2, B5, B20, B50, B100	8 Days	5 days 7/6-7/10
4	B100 Long-term Tests	1500 hours	1000 hours

Note that optimization of the EMx reactor (phase 2) continued into the blend testing (phase 3).

Emissions Test Equipment

TVA used a PACE 400 electrochemical analyzer, by Ametek, which simultaneously measures NO, NO_2, SO_x, O_2, CO, CO_2 and hydrocarbons. The PACE 400 determines the contents of a flue gas stream by continually extracting samples that are routed into a peltier-effect (thermo-electric) cooling system, which removes water vapor from the sample before the sample is passed over electrochemical gas sensors for analysis. The probe and hose assembly contain an integrated thermocouple and water trap, to measure the stack temperature and pressure. A laptop computer was used to capture data from the data analyzer.

Before use of the analyzer, TVA Environmental Technologies Group[3] performed characterization tests with synthetic stack gas to determine the linearity, precision, stability, and response time for NO, NO_2, CO, SO_2 and O_2. The study found that at a 15-second sample scan the linearity and precision were very good with values of less than 1 percent of the test concentration levels. This was better than the factory specifications. As for response time, 90 percent of a step change was registered for NO, NO_2, CO, SO_2 and O_2 within15 to 30 seconds.

[3] *"Report on laboratory testing of THERMOX PACE[2] 400 analyzer with synthetic stack gas mixtures"*, Ralph J. Valente and Vince Van Pelt, TVA, Environmental Technologies, April 6, 2005

The system was calibrated by utilizing standardized calibration gases. The accuracy of the sensor readings are displayed below:

O_2	± 0.3% of gas concentration
CO_2	±5% of reading, 0-2000 ppm ± 10% of reading, 2001-40,000 ppm
NO	±5% or ± 5 ppm of reading, 0-2000 ppm
NO_2	±5% or ± 5 ppm of reading, 0-500 ppm
SO_2	±5% or ± 10 ppm of reading, 0-2000 ppm
Combustibles	±5% of full scale
Pressure	.±2% of reading of or ±0.05 millibar whichever is greater
Stack Temperature	±4 ^{o}F between 32 and 255 ^{o}F ±6 ^{o}F between 256 and 480 ^{o}F ±8 ^{o}F between 481 and 752 ^{o}F

Calibrations were also done regularly during field tests.

Emissions were monitored before and after the EmeraChem EMx Catalyst system. Two ports, at right angles were available for use at each test plane. In early runs, traverses were conducted to look for signs of flow stratification.

Baseline emissions tests were conducted on Ultra-Low Sulfur Fuel Oil (ULSFO) and then emissions tests were conducted with nominal blends of 2%, 5%, 20% and 50 % biodiesel, or B2, B5, B20 and B50. Finally, emissions tests were done with 100% biodiesel or B100.

In presenting test results, the raw measurements (here, in ppm or parts per million) may be thought to be the most reliable, because these can be tied directly to the instrument calibration. However, any air in-leakage into the sampling train can dilute the concentration, and engine controls may change the air

to fuel ratio. Furthermore, the concentration has no direct relevance to the environmental impact, which is more a function of the pollutant mass flow.

The best compromise between usefulness and accuracy is usually found by expressing the emissions results as mass per unit of fuel-energy-input. Thus, power plant measurements are usually expressed as pounds per million BTU.

The pollution load can also be expressed as mass per unit power output. This has the virtue of encouraging efficient use of fuel, but introduces some additional uncertainty, due to the need to accurately measure efficiency, which depends on both fuel input flows and energy output. To ensure these additional measurements are accurate, one must usually operate at a fixed condition over a long period of time, which proved impractical for our tests. Units for these measurements are typically expressed as pounds per MWh for large plants, and grams per brake horsepower hour for engine manufacturers.

The information is presented below in both pounds per million BTU and grams per brake-horsepower-hour, but is always calculated from the fuel-input. When showing output-based numbers, a fixed efficiency is assumed for convenience, although we recognize that actual efficiency will vary, depending primarily on ambient air temperature and pressure.

Results

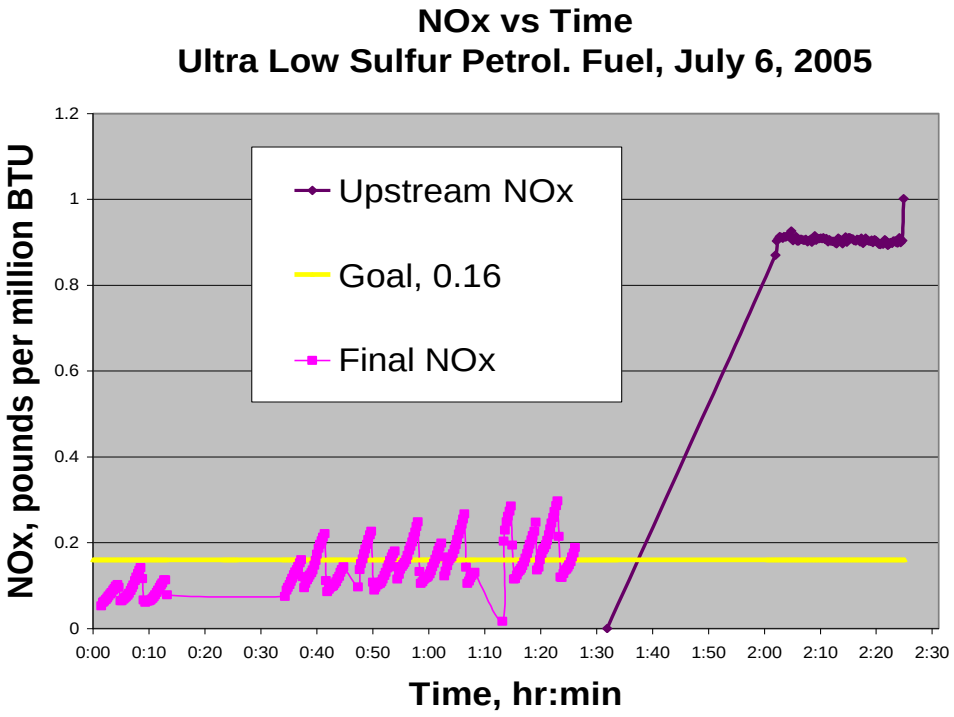
Baseline Tests

Testing began on July 6, 2005, with baseline tests, using ultra-low sulfur (<15 ppm) petroleum diesel. (This was before the <15 ppm Sulfur fuel was widely available, starting in September of 2006.)

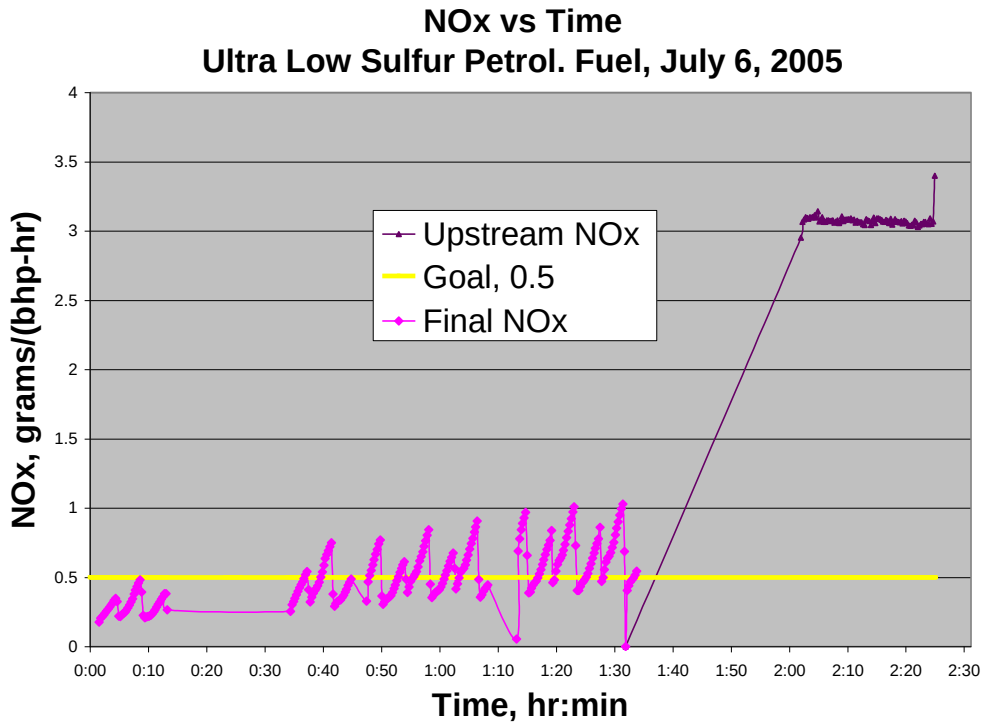
Untreated engine emissions were about 3.1 g/hp-h, well within the manufacturer's specification for NOx emissions of <4.45 g/hp-h.

As discussed by EmeraChem (see Attachment "B", pages 47 and 53) the NOx removal in this test was lower than expected, due to significant leakage of untreated exhaust around the catalyst. This leakage was subsequently discovered and corrected prior to the B20 tests. Despite these leaks, the time averaged NOx emissions (0.131 lbs/million BTU) met TVA's goal (<0.16 lbs/million BTU), although peak concentration (0.266 lbs/million BTU) did not. Results are shown on the next page.

The saw-toothed pattern reflects the regeneration cycle, while the overall upward trend reflects incomplete regeneration, especially in chamber Rx 200. Causes for this incomplete regeneration include the bypass leakage flow and the lower than expected hydrogen output from the reformer (for more details see Attachment "B", page 53). The alternating pattern of high and low NOx peaks reflects the greater bypass flow in chamber Rx200, compared to Rx100.

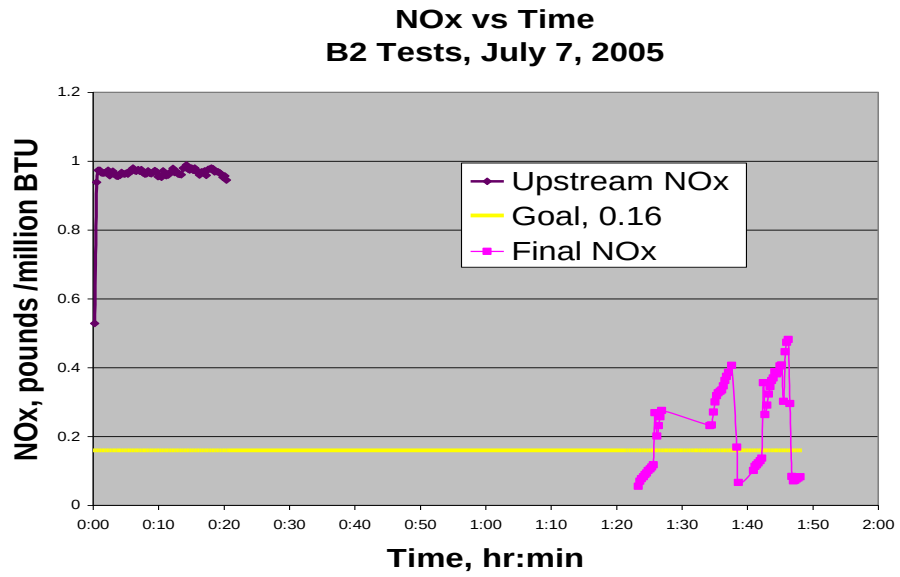


Again as grams per brake horsepower-hour:

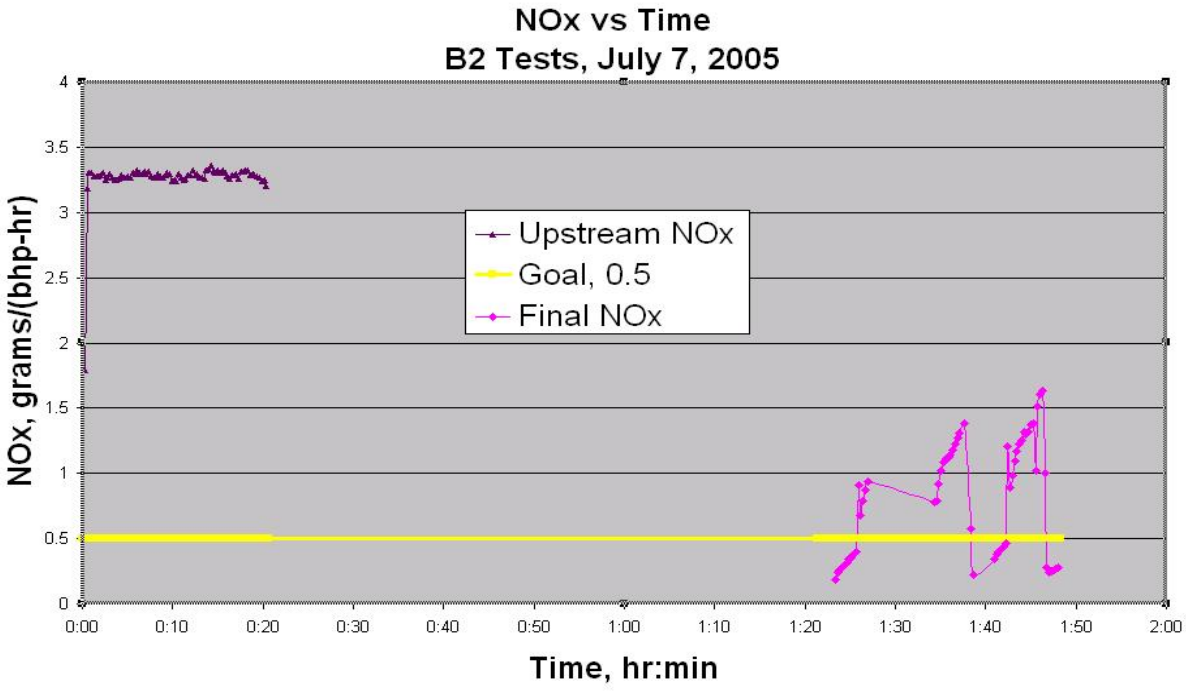


B2 BioDiesel Blend

Testing continued on July 6, with a nominal 2% blend of BioDiesel in Ultra-Low Sulfur Petroleum Diesel. The final NOx averages about 0.24 pounds per million BTU, well above the TVA target. Reasons for this poor performance include lower than expected hydrogen output from the reformer, leakage flow bypassing the catalyst, and incomplete washing of the catalyst. More details are given in EmeraChem's report (see Attachment "B", page 53).

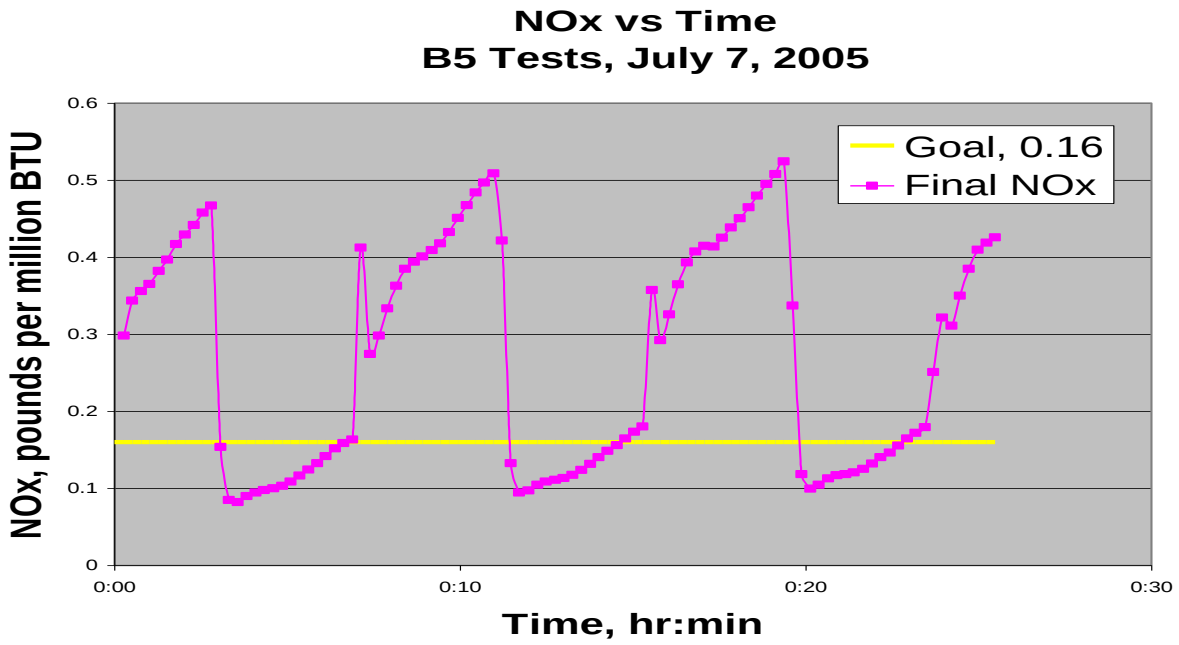


Based on a 2002 study by EPA (EPA420-P-02-001), we had expected the untreated NOx emissions to increase by about 10% for B100, and a proportionately smaller increase (<1%) for B2. In contrast, our B2 test showed a 6.87% increase. While still well below the manufacturer's specification, untreated NOx emissions increased from 3.07 g/hp-hr for petroleum diesel to 3.28 g/hp-hr. for B2.



B5 BioDiesel Blend

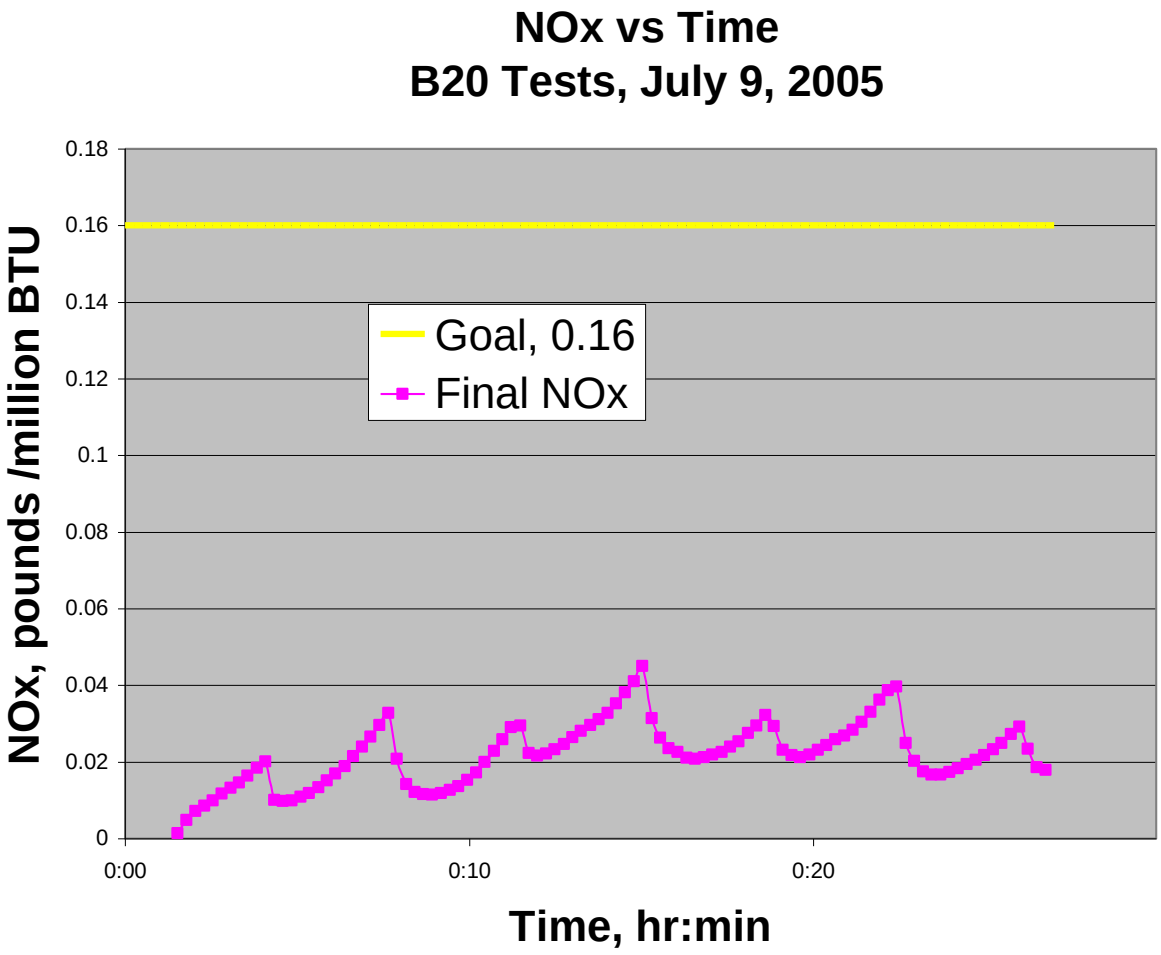
Later the same day, July 6, testing began on a nominal 5% BioDiesel blend. Results are shown below. Again, it is clear that performance is deteriorating, and the same causes are suspected, namely: lower than expected hydrogen output from the reformer, leakage flow bypassing the catalyst, and incomplete washing of the catalyst. Obviously, the NOx removal goal was generally not met, although it was met periodically for a few minutes.



After completion of the B5 test, EmeraChem re-washed the catalyst and ***reworked the catalyst chamber***. Bypass flow was restricted by the use of bars to straighten and stiffen the back wall of the catalyst chamber and act as a labyrinth seal. Gaskets were added to the door to improve sealing on the front side. The reformer was also modified and refurbished. Details are given in Attachment "B", page 54.

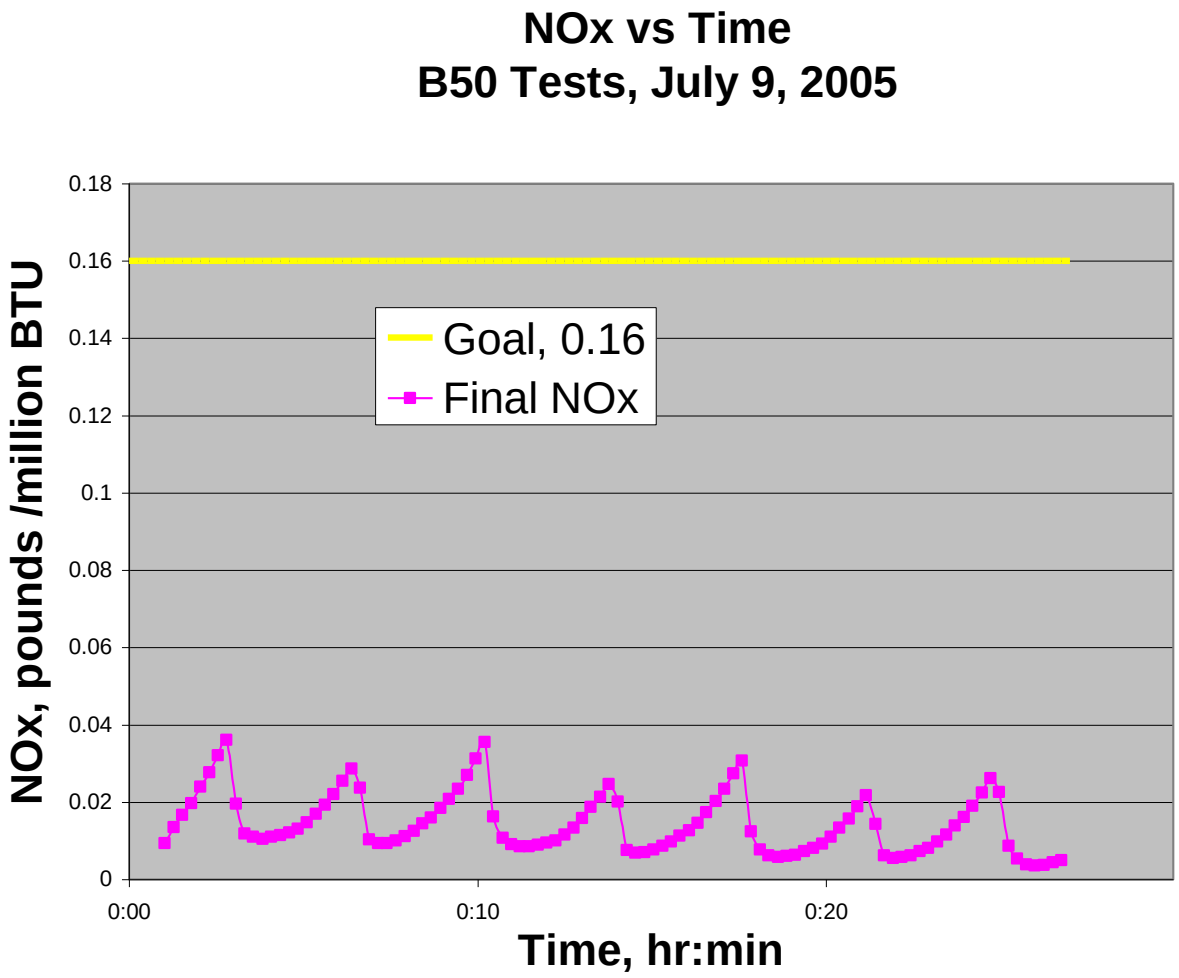
B20 BioDiesel Blend Testing

Testing resumed on July 9, using a nominal 20% BioDiesel blend. NOx removal results were excellent, and far exceeded our goal



B50 BioDiesel Blend Testing

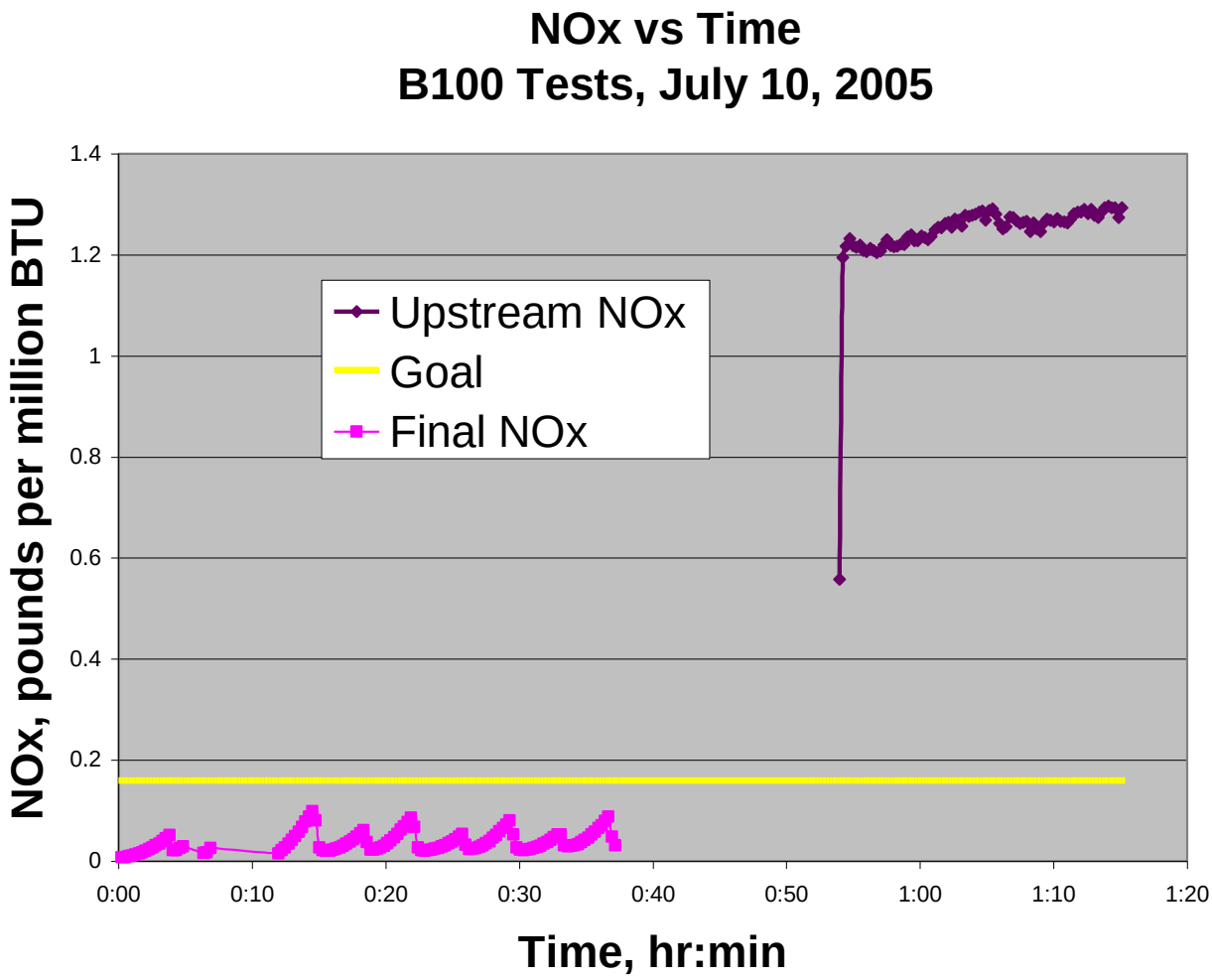
Testing continued on July 9, using a nominal 50 % BioDiesel blend. Again, NOx removal results were excellent, and far exceeded our goals.

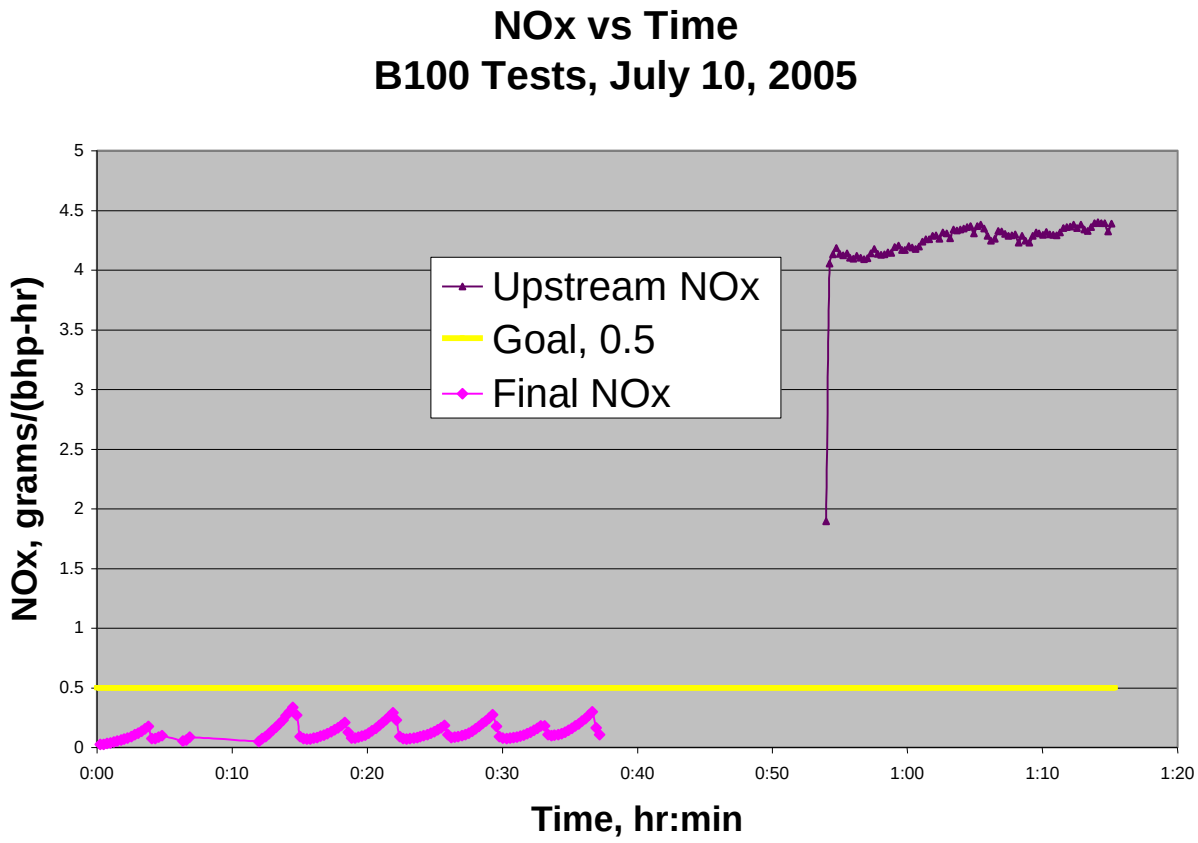


B100 BioDiesel Testing

Testing continued on July 9, using 100 % BioDiesel. Again, results were excellent, and the TVA target was met. The results are displayed on the in two forms: pounds/million BTU, and grams per brake-horsepower-hour.

The untreated NOx emissions average 4.23 g/hp-hr, using B100. This compares to 3.075 g/hp-hr using Ultra-Low Sulfur Petroleum Diesel, and 3.07 g/hp-hr using B2. NOx emissions are apparently a non-linear function of the percentage biodiesel, and using B100 increases the NOx emissions by about 38% compared to petroleum diesel. (Recent studies have shown that biodiesel does not increase NOx emissions in some engines, and this may depend on the engine's timing adjustment.)





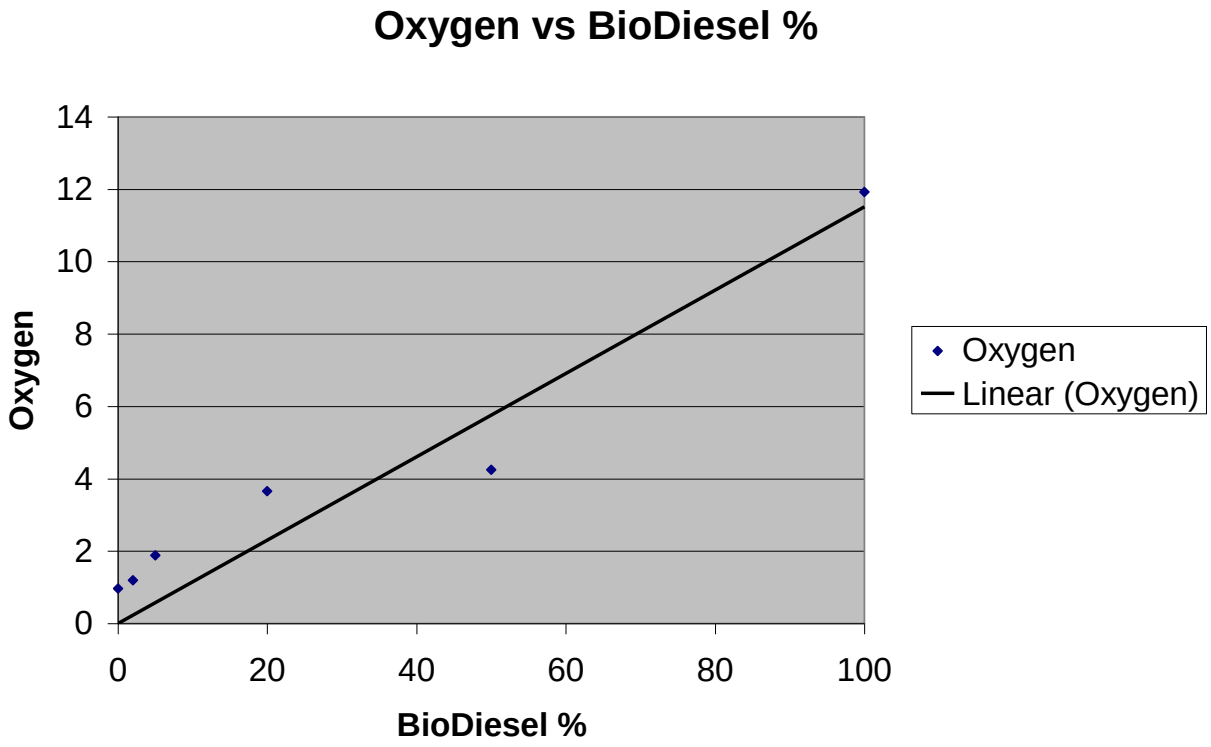
TVA had planned to follow-up with two additional emissions test campaigns during the B100 endurance runs, but these tests were postponed, and then cancelled because of the reformer failure. Nevertheless, we conclude that if a reliable reformer or other source of hydrogen can be developed, a system similar to that demonstrated here should be capable of meeting TVA goals for NOx emissions control, when fueled with any blend of biodiesel and low sulfur petroleum diesel.

Fuel Characterization Tests

In order to make the stoichiometric calculations required for emissions analysis, one must first analyze the fuel to determine an empirical formula. For the fuels used in this work, the major constituents are carbon, hydrogen and oxygen. This analysis was done by TVA's central laboratory, using standard methods. The results are tabulated below:

Sample Description	ULSFO	B02	B05	B20	B50	B100
Carbon wt.%	85.2	85.06	84.57	83.08	82.65	76.23
Hydrogen wt.%	13.83	13.75	13.55	13.26	13.1	11.85
Nitrogen wt.%	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
BTU/lb	19801	19674	19649	19212	18679	16725
Ash	<0.001	<0.001	<0.001	0.001	0.003	--
Density g/ml	0.8195	0.8205	0.8219	0.8305	0.8398	0.8785
Oxygen by dif, wt %	0.97	1.19	1.88	3.659	4.247	11.92

Oxygen content is plotted below vs. the nominal percentage BioDiesel. It appears that the B5 and B20 blends were higher than nominal BioDiesel, while the B50 was lower.



Samples were sent to two labs to help understand this situation. Findings are tabulated below:

Sample Name	Nominal Blend	Magellan	Minnesota	% Methanol
MG-B	2%	1.40%	1.87%	
MG-D	5%	11.00%	4.85%	
MG-C	20%	25.10%	20.76%	
MG-A	50%	32.60%	36.96%	
MG-E	100%	93.20%	96.95%	~3%

Jim Hedman of the State of Minnesota's Department of Commerce, Weights and Measures Division, was able to identify a problem with the B100 blend; it contained about 3% Methanol! (His analysis is detailed in Attachment "A") With levels this high, the samples would not have passed the flash point

test. Taking into account for the methanol effect, the blend ratios appear to have been reasonably accurate, except for the B50, which was clearly an outlier.

Because the methanol issue heightened our sensitivity to the issue, we began routinely gathering biodiesel samples and having them analyzed for conformity to a subset ASTM standard D-6751. As discussed earlier (Report, page 8), samples were frequently found to have excess glycerin. Excess methanol was not a problem in later samples.

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